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INVESTIGATION VERSUS PROPAGANDISM

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The case of the ancient pottery-makers of Vero, Florida, seems really quite worthy of becoming a *cause célèbre*. It has already passed through two stages and is now well on in a third. The purpose of this paper is to urge that this third stage be closed at once by common consent and that the inquiry be pushed on into a fourth stage. The first stage embraced the discovery, the preliminary examinations, and the presentation of the case to the scientific public; the second covered some concerted field investigations by interested specialists and the publication of their results in symposia; in the third stage there has developed a tendency to lapse into isolated discussions with a trend toward controversy, as well as a trend toward premature propagandism. What should constitute the fourth stage may best be considered after such a brief review of what has been presented as shall make clear the status of the case at the close of the stages already past.

STAGE I. THE ANNOUNCEMENT AND PRELIMINARY PRESENTATION

The discovery, as is so often the case, was made incidentally in the progress of industrial work. The preliminary inquiries were of the usual type and the initial announcement was made to the

appropriate scientific jury through the venerable *American Journal of Science*. The subject was thus given a fitting introduction and a distinctly scientific aspect from the outset.

The presence of vertebrate fossils in deposits of a late age at Vero was learned as early as 1913. Fossil human remains were found in association with these in 1916. The first announcement by Dr. Elias H. Sellards, state geologist of Florida, was made in July, 1916. A supplementary statement in *Science* was made in October, 1916, and an official report in the *Eighth Annual Report of the Florida Geological Survey*. This stage presents an excellent example of the composite work that falls to the lot of state geologists and their associates, in which it is often necessary for a single inquirer or a small group to pass upon very complex phenomena whose ideal treatment calls for the co-operative work of many specialists.

The case as developed in this introductory stage.—Beneath the site of the finds the basal formation is a marine marl (coquina) commonly referred to a late Pleistocene age, though all or essentially all its fossils belong to living species. It spreads under the whole neighborhood, so far as present evidence goes, and forms an excellent basal datum plane. On this basal formation the retiring sea built sand flats and beach ridges, while the wind built dunes, the whole forming a low belt of finishing deposits. These lie along the margin of the present mainland, while across a sea inlet about a mile wide, lies a barrier reef now in process of building which forms the outermost coast line of the Atlantic. The low ridged belt on the edge of the mainland is known in the discussion as Vero Ridge.

After the withdrawal of the sea, surface wash deposits and fresh-water marls gathered to some extent in the shallow basins of these finishing formations. At the same time a small drainage system was established near Vero, now known as Van Valkenburg's Creek. The main stream channel was formed by the junction of two branches which in turn were sub-branched. All these features seem to have been determined mainly by the ridglets, swells, and hollows of the retiring sea deposits. The branchlets, however, reach back into a marshy tract west of the Vero Ridge. The united drainage from the north meets that from the south nearly head-on and the

two unite into a trunk stream flowing eastward to the sea about a mile away. The particular site of the human and vertebrate remains lies near the junction of the two branches.

Before the remains under debate could have been buried in the way in which they were found, the creek must have excavated a relatively broad flat with such low gradients as to permit aggradation. The average depth of the aggraded creek deposits is about six feet. They consist chiefly of washed sand and vegetal muck and other débris, with some fresh-water marl. They are thought by Dr. Sellards and most others to be divisible into two layers, a lower, No. 2, consisting of three to four feet of sand and muck, with fresh-water marl; while the upper, No. 3, consists more largely of muck and vegetal débris with a less proportion of sand, layer No. 1 being the marine marl below. The upper layer, No. 3, cuts here and there into No. 2, sometimes cutting entirely through it into the marine bed below.

In this first stage of inquiry, parts of two human skeletons were recognized, one of which was referred by Dr. Sellards to the lower creek deposit, No. 2, and the other to the upper creek deposit, No. 3. It was urged strongly in the initial papers that the scattered condition of the bones, as well as their other relations, shut out the probability, if not the possibility, of intrusive burial. On the other hand, it was urged that the human remains could not have been washed in from outside sources, or even transferred from the one layer to the other in any notable degree, because of the unworn state of some of the fossils and the fragile condition of others. A considerable number of the vertebrates found in the lower layer were identified as extinct forms; some of them had been usually referred to rather early stages of the Pleistocene. A smaller number of extinct vertebrates were found in the base of the upper layer, at about the same level as that of the human skeleton referred to that layer. The bones of the extinct vertebrates and of man were both found to be mineralized in much the same degree. With the human bones were found chipped stones, bone implements, and fragments of pottery.

On the basis of the evidence thus gathered the lower creek deposit, No. 2, was referred confidently ot the Pleistocene; the

upper layer was regarded also as probably Pleistocene, but some reservation was expressed respecting this.

STAGE II. CONCERTED INVESTIGATION AND CO-ORDINATE PUBLICATION

Closely following this introductory stage Dr. Sellards extended cordial invitations to various specialists to inspect the deposits and the material already gathered from them, and to join in further inquiry. Two field conferences followed. The earlier and larger was held in October, 1916, participated in by Dr. George G. MacCurdy, anthropologist of Yale University, who gave special attention to the archaeological evidence; Dr. Aleš Hrdlička, anthropologist of the U.S. National Museum, who gave special attention to the human bones; Dr. Thomas W. Vaughan, geologist in charge of the coastal plain investigations of the U.S. Geological Survey, who viewed the matter from the standpoint of the regional geologist; Dr. Oliver P. Hay, research associate of the Carnegie Institution in Vertebrate Paleontology, who studied in particular the evidence of the vertebrate bones; Dr. Rollin T. Chamberlin, associate professor of dynamic geology at the University of Chicago, who gave special attention to the physico-dynamical vestiges of the deposits and their import; Assistant Geologist Herman Gunter, of the Florida Geological Survey; Mr. Isaac M. Weills and Mr. Frank Ayers, citizens of Vero, who had taken an active interest in the discovery from the outset.

The results of this first conference were gathered into a symposium in the January-February, 1917, number of this *Journal*. The contributions were from Dr. Elias H. Sellards, embracing a report by Dr. Robert W. Shufeldt on the fossil birds (pp. 4–24); Dr. Rollin T. Chamberlin (pp. 25–39); Dr. Thomas W. Vaughan (pp. 40–42); Dr. Aleš Hrdlička, including a letter from Professor William H. Holmes (pp. 43–51); Dr. Oliver P. Hay (pp. 52–55); and Dr. George G. MacCurdy (pp. 56–62).

The second conference was held in March, 1917, Dr. Sellards again serving as host, participated in by Professor Edward W. Berry, paleobotanist of Johns Hopkins University, who gave especial attention to the testimony of the fossil plants; Dr. Rollin

T. Chamberlin, of Chicago, who returned for a more critical examination of certain features than was possible on the former visit; Assistant Geologist Herman Gunter, Mr. Isaac M. Weills, and Mr. Frank Ayers.

The results of the second field conference appeared in the October-November number of the same volume of this *Journal*. The contributions to this were from Dr. Elias H. Sellards (pp. 659–60), Dr. Edward W. Berry (pp. 661–66), and Dr. Rollin T. Chamberlin (pp. 667–83.)

The development of the case in connection with the two field conferences and the symposia.—It is aside from the purpose of this discussion to review these papers as personal contributions; we merely wish to trace the evolution of the case by contributions which represent different points of view and different methods of inquiry. We shall therefore merely try to bring out the most vital features of these papers as an additional résumé of the official composite work and as contributions from the standpoints of physico-dynamic inquiry, of vertebrate paleontology, of human osteology, of the human artifacts and industries, of fossil plants, and of other sources of evidence.

Preliminary to such outline, it may be helpful to remark that the Pleistocene age of the ancient men of Vero was pressed to the front as the specially vital question of the case at the outset. This specific question gave trend to the inquiry and to the contributions we are to sketch. Now, a dominating question of this kind inevitably forces the discussion to center, consciously or unconsciously, on the nominal or the conventional aspects of the case implied by the technical term Pleistocene, rather than on the strict realities involved in the case. The crux of the problem is thus made to hang more or less largely on technical terms. These in turn depend on the criteria that are accepted as guides in fixing the use of these terms. This grows naturally out of the history of attempts to show that man existed in America at certain early stages.

Three things are to be kept in mind in interpreting a discussion dominated by such a foremost feature: (1) the term Pleistocene is not used in precisely the same sense by all writers, (2) the criteria used in establishing the technical age are subject to challenge, and

(3) there are more vital questions than the simple Pleistocene or non-Pleistocene age of man in America.

Distinct foreshadowing of these points appeared in the conferences and symposia. The most significant of these was a rather distinct challenge of the trustworthiness of some of the criteria in so far as applicable to the case in hand, though heretofore regarded as good; modifications of the accepted criteria in certain vital aspects were suggested. This of course really means that they are not criteria at all, as used, and will become such only when properly revised. The stress of skepticism was thereby put on the criteria; and so the trustworthiness of these comes to the front as really the most vital feature of the case.

Now the criteria originally used in determining the divisions named Eocene, Miocene, Pliocene, Pleistocene, and Recent were made to rest on the numerical proportions of living species represented in the respective formations, viz.: in the Eocene, less than 5 per cent living species; in the Miocene, 20 to 40 per cent; in the Pliocene, more than half living species; and in the Pleistocene, about 95 per cent.[1] The species counted were chiefly, though not exclusively, marine. As the rates of change of marine forms differ from those of land forms and those of the land forms differ among themselves, this numerical basis was found unsatisfactory from the outset. As the real needs of the case developed, these original criteria were abandoned more or less completely and are now used only in a residual way in certain modified forms and in certain special situations. So far as the Pleistocene is concerned, the numerical paleontological criteria have been replaced to a large extent by physico-dynamic criteria drawn from the great ice invasions. This replacement constitutes a radical and significant departure. It is a part of the general movement to make the causal and world-wide agencies the basis of classification rather than their products, which vary with regional conditions.

For the close of the Pleistocene, in particular, the retreat of the continental glaciers from the plains of Europe and North America and the accompanying climatic effects are now the more generally accepted criteria. The substages of the Pleistocene are

[1] See Dana's *Manual of Geology*, fourth edition (1895), pp. 879–880.

marked off naturally by the successive ice invasions and retreats, because these very profoundly affected all the life in the middle and northern latitudes of the Eastern and Western hemispheres, while indirectly they greatly influenced the life-conditions in the more southerly latitudes.

Though these new physico-dynamic criteria do not afford very sharp lines of demarcation, they are in reality sharper than the paleontological criteria they have replaced. Changes of species are slower, and their interpretation more uncertain, than the changes in the great ice-sheets. It will help to show the real significance of the diverse interpretations of the Vero case if we here give a table of the relative dates of the several glacial stages compiled from estimates made by the more experienced students of glacial phenomena. Of course these are by no means final figures; they are held subject to very considerable changes as additional data are gathered; but they may be regarded as indicating tentatively the order of magnitude of the time-distribution of the glacial stages. We have derived from the compiled estimates what seem to us conservative minimum estimates.

ESTIMATED TIME-STAGES OF THE PLEISTOCENE PERIOD

	Compiled Estimate	Minimum Estimate
Close of Pleistocene, beginning of Recent	25,000 yrs. ago	20,000 yrs. ago
Climax of Late Wisconsin glacial stage	40,000 " "	30,000 " "
Climax of Early Wisconsin glacial stage	95,000 " "	60,000 " "
Middle of Peorian interglacial stage	135,000 " "	90,000 " "
Climax of Iowan glacial stage	180,000 " "	105,000 " "
Middle of Sangamon interglacial stage	260,000 " "	155,000 " "
Climax of Illinoisan glacial stage	340,000 " "	190,000 " "
Middle of Yarmouth interglacial stage	500,000 " "	275,000 " "
Climax of Kansan glacial stage	660,000 " "	330,000 " "
Middle of Aftonian interglacial stage	900,000 " "	450,000 " "
Climax of Jerseyan glacial stage	1,200,000 " "	540,000 " "

Maximum estimates should probably be double the compiled estimates in the later stages and more than double in the earlier stages.

Now, if we take the extreme ages to which the fossils at Vero have been referred by different members of the conferences, the

total range, using the minimum estimates of our table, is over four thousand centuries, and yet the deposits embrace a thickness of only six feet, the lowest layer of which was not deposited until some time after the last retreat of the sea from the mainland. This serves to indicate the stress the case has put on accepted criteria. With this aspect of the case in mind, let us note the essence of the several contributions to the symposia.

Further contributions from the viewpoint of the state geologist.—The two further contributions of Dr. Elias H. Sellards have the same import as his earlier papers already sketched. He, however, adds certain more declared statements that bear strongly on intrusive burial, on transfer by water and other natural agencies, and on original burial where now found.[1] Among these are the absence of whole skeletons, the infrequency of even complete individual bones, the scattered and imperfectly preserved state of the bones, their frequent and often sharply broken condition, together with evidence that "in the case both of the human and of the other vertebrates the bones were more or less disturbed after they had lost enough of their organic matter to become sufficiently brittle to break as they were moved about by water before reaching their final resting place."[1] "In the number of bones that have been obtained representing a single individual there is observed no important difference between the human and the other animals."[2]

The contribution from the physico-dynamic inquiry.—At the first conference an attempt was made by Dr. Rollin T. Chamberlin[3] to discriminate as closely as practicable what had been done at the successive formative stages, whether constructive or destructive, so as to give an analytical basis for the treatment of the special question under debate and for reconciling, so far as might be, the seemingly incompatible import of different criteria as then interpreted. The several episodes distinguished were as follows: the already well-recognized coquina marl, the datum base (Sellards' No. 1); the sand-capping over this and the formation of beach ridges and dunes; the gathering of fresh-water marl deposits, containing vertebrate remains, in the hollows of this low ridged

[1] Symposium 1, *Jour. Geol.*, XXV (January-February, 1917), 1, 22.

[2] *Ibid.*, p. 23. [3] *Ibid.*, pp. 25–39.

tract; the formation back of the ridge—more or less contemporaneously with this—of a more extensive flat area with boggy tendencies, the most significant feature of which is an indurated black sand, from which pebbles ranging up to "cannon balls" were later derived and borne into the lower and upper fossil-bearing layers (Sellards' No. 2 and No. 3); the development of the drainage system of Van Valkenburg's Creek, partly in the one and partly in the other of these two upland formations; the excavation of the creek trench to a breadth and gradient suitable for the beginning of aggradation; the first stage of aggradation (Sellards' layer No. 2); and the second stage of aggradation (Sellards' No. 3).

On the basis of this analysis, a hypothesis was proposed which seemed to reconcile some of the apparently conflicting imports of the fossils in the lower and upper parts of the creek deposits. It postulated that the oldest extinct mammals came into the region as soon as it emerged from the sea, and were buried in the hollows and flats of the ridged tract, and more especially in the poorly drained, flattish area lying west of the Vero Ridge, whence at some time notably later they were carried into the creek deposits much as the black pebbles from the indurated sandstone of the same area were found to have been.

No time was available during the first conference after this hypothesis was formulated for testing it, and it was offered in this state in the first symposium as a hypothesis of reconciliation, and the earliest opportunity sought to put the hypothesis to the test. On his second visit, Dr. Chamberlin found the bog deposits back of the ridge essentially barren of fossils, suggesting conditions either inhospitable to life or unfavorable for its preservation. In his contribution to the second symposium the part of the hypothesis relating to the bog deposits was therefore frankly laid on the shelf; nor was the alternative phase which made the upland marl beds of other parts of the tract the source of the older fossils of the creek deposits further urged, because fossil-bearing deposits of this kind were not found in available situations, though they occur elsewhere. The part played by this stage between the retreat of the sea and the aggradation on the bottoms of Van Valkenburg's

Creek must of course yet be worked out and put in its place in the history of the formations at Vero.

On the shelving for the time being of this hypothesis of reconciliation an endeavor was made to detect such physical possibilities for faunal deployment as might be implied by the creek deposits themselves, thin as they are. The inquiry brought out the fact that the exposed sections of the creek filling showed distinctly more reworking in some portions than in others, together with the suggestive fact that where the layers were least irregular a fair line of distinction could be drawn between an upper and a lower portion, but that where there was most evidence of scour-and-fill the line of distinction between upper and lower layers was more obscure and at points quite uncertain. Discussion of the precise line of division between the layers, among the investigators while on the ground, brought out notable differences of opinion, and furthermore opinions were more or less changed as the inquiry went on. As the result of such changes of opinion, the dividing line was more often shifted downward than upward.[1] The effects of scour-and-fill in the more disturbed portions of the deposit were found very notable, and they were more pronounced in and near the critical horizon between the upper and lower deposits than at other levels. Scour holes were traced well down into the horizon assigned to the lower layer (No. 2), and even entirely through it into the marine marl below. It was observed that coquina shells had been carried up across the whole horizon of the lower layer and redeposited in the horizon of the upper layer. A careful excavation of a scour hole led to the successive placing of the dividing line between the layers at lower and lower levels, as the work went on, and in the end to the disclosure at the bottom of the hole of the carapaces of two turtles, apparently put there by the swirling water-hole action.

It was further observed that the portions of the creek deposits most marked by scour-and-fill action were the portions richest in human and extinct vertebrate remains, suggesting some causal connection between the scour-and-fill action and the accumulation of the relics.

[1] For details and illustrations see Symposium 2, *Jour. Geol.*, XXV (October-November, 1917), 673–82.

It appeared further that, while some of the relics were very fragile and could only be supposed to have been moved by very gentle processes—if moved at all after they reached their present condition—most of such fragile material belonged to the lower layer or to the more undisturbed portions of the upper layer, and so a correlation between the condition of the layers and the condition of their content was suggested.

The question of possible transference was further affected by finding relics of the same species as those to which the fragile specimens belonged in a condition that could easily stand transportation. There remained, however, in some parts of the deposit sufficient fragile material to indicate that it had not undergone more than the most gentle handling since the fragile state was acquired. Such cases, however, were largely in the lower layer and in the less irregular parts of the upper layer.

On the whole, this closer inspection of the deposits and their fossil content seemed to strengthen the presumption that some of the relics of the extinct animals were deposited in the lower layer when that layer was taking on the form it now bears and that these relics were not introduced by any subsequent process.

The import of these observations had the effect of throwing the stress of interpretation on the dividing tract between the two layers and on the upper layer. The termination of deposition of the upper part was definitely fixed at the year 1913, when the digging of the canal stopped the normal work of the creek. It appeared that such bones of extinct vertebrates as were found in this upper layer were much scattered; that their number was small relative to the whole number in the original skeletons, being commonly a few teeth, or a lower jaw, or one or two other bones, which did not seem to exclude some reworking but rather to imply it.[1]

In the light of this inquiry along physico-dynamic lines, the balance of evidence, taken all together, seemed to Dr. Chamberlin to favor the reference of such portions of the creek deposits as bear human relics to the later stage of filling, since all observers

[1] For specific details on these critical points see Symposium 2, *Jour. Geol.*, XXV (October-November, 1917), 676–82.

were agreed that the upper fill actually penetrates deep into the lower fill at several points, while the more critical examinations aided by excavations increased the evidence of such penetration.

Such seeming to be the import of the physical evidence, the testimony of the human bones and of the relics of human industries interpreted on their own grounds seemed to furnish the most available and precise criteria of the paleontological order that was available, and among the human relics the pottery seemed to give the most specific evidence. And so, adding the anthropologic and archaeologic testimony to the physico-dynamic evidence, Dr. Chamberlin concluded that the time of deposition of the upper layer belonged within the Recent Period, perhaps not dating back beyond the mid-Recent stage.

The contribution from vertebrate paleontology.—Dr. Oliver P. Hay identified the vertebrate fauna found in the lower part of the creek deposits at Vero as

> essentially that which is found in the Aftonian interglacial beds of Iowa and in the Equus beds of the Plains. From the latter, this fauna may be followed into Texas, thence eastward into Florida and South Carolina. Of this fauna, two species of elephants, the common mastodon, *Megalonyx*, and the giant beaver continued on until after the Wisconsin glacial stage. Other species, the saber-toothed tigers, *Equus complicatus*, the tapirs, most of the extinct bisons, and *Mylodon* probably disappeared before the Wisconsin glacial stage. In the earlier Pleistocene deposits only are found *Elephas imperator*, camels, several species of horses, and many edentates. At Vero have been found three species of horses, at least four edentates (including *Mylodon*), and a camel. *Chlamytherium* was originally found on Peace Creek in deposits which were then supposed to be Pliocene. In the same deposits was found a jaw containing a tooth of an elephant which is quite likely *E. imperator*. This species has not yet been found in No. 2 at Vero, but about three miles west of the place Sellards found a lower jaw which belongs probably to this species. It is known from Dallas County, Alabama, and from Charleston, South Carolina. [Dr. Hay regards it and camel remains as particularly indicative of the Aftonian fauna.] It is possible that this fauna continued on for another stage or two without great change, but by the time of the Illinoisian drift it had become essentially modified.[1]

Dr. Hay regarded the vertebrate fauna of deposit No. 2 as primary, thus making the deposition of the beds as now seen also Pleistocene in age.

[1] Symposium 1, *Jour. Geol.*, XXV (1917), 54–55.

> No place was discovered from which the included bones and teeth might have been washed in, nor do they in general have the appearance of transported fossils. These bony remains are in what may be regarded as a normal condition; as when, in a little valley furnishing food and drink and shade, herbivorous and carnivorous species had resorted and perished there for thousands of years. In a normal way their bones have almost all fallen into dust. Some, buried under somewhat favorable conditions, endured longer, but softened and were trampled into fragments by succeeding generations of elephants, mastodons, horses, bisons, huge ground sloths, and smaller forms. Only the most favored and protected bones and teeth have endured to the present, mostly scattered, but sometimes remaining associated with others of the same skeleton.[1]

Dr. Hay regarded the lower part, at least, of No. 3 as also Pleistocene.

> This deposit is somewhat more difficult to work for fossils, but it has furnished almost all the forms that are found in No. 2. It is not improbable that some bones and teeth were redeposited from the lower stratum, but not, I think, any considerable or essential portion of them.[2]

In the *Ninth Annual Report of the Florida Geological Survey*,[3] Dr. Hay treats more fully the vertebrate remains from the beds in question, mostly those of the upper layer, and reaffirms his belief not only that the fossils represent an early or middle Pleistocene fauna, but that the deposits in which they are now embedded are early and middle Pleistocene in age also.[4]

Dr. Robert W. Shufeldt described the fossil bird bones but does not discuss their bearing on the age of the deposits further than to indicate that some of the species are extinct.[5]

Contribution from the standpoint of paleobotany.—In his report on the fossil plants, Dr. Edward W. Berry says that "plant remains in the form of laminae of impure peat or scattered fruits, chiefly acorns, are present from the bottom to the top of the deposits overlying the shell marl which forms the base of the section. The lower sands (designated No. 2 by Sellards) have yielded

[1] Symposium 1, *Jour. Geol.*, XXV (1917), 52.

[2] *Ibid.* [3] Pp. 43–68.

[4] *Ninth Annual Rept., Florida Geol. Survey*, p. 67.

[5] Symposium 1, *Jour. Geol.*, XXV (1917), 18–19; *Ninth Annual Rept., Florida Geol. Survey*, 1917, pp. 35–42.

no leaves and but few acorns, but the upper bed (designated No. 3 by Sellards) contains many leaf layers alternating with sand laminae."[1]

Recent and extinct mammalian and other bones occur in both layers, and human remains are also found in both beds. After a thorough study of the local sections and the paleontologic evidence I am convinced that there is no hiatus between beds Nos. 2 and 3 and that there is no great difference in age from the bottom to the top of the section, although it records changing physical conditions and necessarily becomes gradually more and more recent as the top of the section is approached. The lower sand marks the recession of the sea in which the underlying shell marl was formed. The upper beds (No. 3) mark successive seasonal layers of valley filling in the narrow valley of a small stream. This stream was apparently always small, and the marvelous abundance of fossils at this one point seems to be due to a bar or sink-hole or similar cache formed near the junction of the two lateral branches which united near this point to form the main stream. The determinable plants are represented almost exclusively by fruits or seeds, as the leaves, with the exception of the coriaceous oaks, which are abundant, were too thoroughly decayed before they were buried to retain their identity.[2]

After a summary grouping and discussion of species, Dr. Berry concludes:

In my judgment and in the ordinary acceptance of that term this flora is unquestionably of late Pleistocene age.

Regarding its bearing on the interesting problem of the age of the human and associated mammalian and other remains at Vero, my study of the locality furnishes the following somewhat categorical conclusions. The underlying shell marl which forms a definite and undisputed datum plane, is late Pleistocene in age. Its species all exist in near-by waters at the present time. . . . . It follows that the vertebrate remains which are so numerous at Vero cannot possibly be of Middle or Early Pleistocene age unless they are regarded as having been reworked from older deposits, and I cannot conceive that this was possible, nor do the vertebrate paleontologists who have examined the deposits consider that such was the case. . . . . Nothing is more reasonable than to suppose that the larger elements in the Middle Pleistocene fauna of more northern areas should have lingered for thousands of years in this more genial southern clime until the presence of man in considerable numbers and the changing climate, as is attested by the fossil plants, should have brought about the extinction of a large percentage of the fauna. The fauna itself confirms the rather limited data furnished by the fossil flora of this change in climate,

[1] Symposium 2, *Jour. Geol.*, XXV (October-November 1917), 661.

[2] *Ninth Annual Rept., Florida Geol. Survey*, 1917, pp. 19–20.

since it indicates a more mesophytic habitat than exists today in the vicinity of Vero. . . . . I therefore see no reason to doubt that relatively modern men were contemporaneous with this partially extinct fauna of Middle Pleistocene aspect which survived in Florida to the late Pleistocene. With regard to the exact age of the Vero deposits there are, it seems to me, but two alternatives, and these apply equally and are in large part derived from a study of the physiography and the faunas and floras of the corresponding topographic forms in the other states of the Coastal Plain. These alternatives are that they are about the same age as the Peorian interglacial deposits of the Mississippi Valley or are immediately post-Wisconsin and correspond with what the Scandinavian geologists have named Litorina time.[1]

Contribution from the viewpoint of the fossil beetles.—Recently a contribution relative to the fossil beetles has been made by H. F. Wickham, which is given a place here. The following is the author's summary:

Two conclusions seem to be warranted after a study of the beetle fragments. The first is that there is nothing to indicate any particular difference in climatic conditions in Florida then and now, since the assemblage of genera is the same as one might expect to find in a stream valley there today. The nearest relatives of the species are still characteristic members of the Floridian fauna and many of them are apparently identical. Second, it seems evident that there has been some change in minor characters of sculpture, since it is not possible to match certain of the fossils exactly with modern forms. In view of the fact that other researches indicate that insect evolution has been extremely slow, so that many species, even as old as the Tertiaries, are rather difficult to discriminate from their modern allies, no more marked divergence would be anticipated.[2]

Contribution from the viewpoint of regional geology.—Obviously the formations that occupy the adjacent coastal region and reach back to the glacial deposits have a vital bearing on the interpretation of the Vero deposits, and so the problem of interpretation as seen from the standpoint of the geologist in charge of the coastal plain investigations of the U.S. Geological Survey, Dr. Thomas W. Vaughan, constitutes a contribution on a distinct basis. The following is the essence of his conclusions: "The occurrence of artifacts and human bones in association with Pleistocene fossils does not prove the Pleistocene age of man," since previous investigations have shown that human artifacts and bones, by many

[1] *Ninth Annual Rept., Florida Geol. Survey*, 1917, pp. 31–33.

[2] *Amer. Jour. Science*, May, 1919, p. 355.

agencies, natural and artificial, have been carried below the surface and become imbedded in unconsolidated deposits. "The only indisputable geologic proof of the Pleistocene age of man must consist in finding a continuous undisturbed bed or layer of demonstrable Pleistocene age above the human remains."[1] In view of the questions that are still undetermined, he advises suspension of judgment for the present.

Contribution from the testimony of the human bones.—Dr. Aleš Hrdlička, after describing critically the human bones, expresses the unreserved opinion that they do not differ in any essential respect from those of the modern Florida Indians.[2] He argues in favor of the human burial of the remains, but this, of course, is geological rather than anthropological and is only incidental to his testimony as an expert student of the human skeletons themselves. He reaches the conclusion that the human bones found at Vero may well be prehistoric, and date from the early part of the occupation of the Florida peninsula by the Indians, but that no proof is furnished by the circumstances of the find, or by the human bones themselves, which would relegate the latter to an antiquity comparable with that of the extinct fossil remains with which they are associated.

Contribution from the viewpoint of the human artifacts.—In a note inclosed in Dr. Hrdlička's paper, Dr. William H. Holmes reports on twenty pieces of pottery collected near the human bones, that

> they represent moderately small, undecorated vessels, apparently simple bowls such as were in common use among the Indian tribes of Florida. Compared with corresponding plain vessel fragments from Florida sand mounds and from occupied sites generally, no significant distinctions can be made; in material, thickness of walls, finish of rim, surface finish, color, state of preservation, and size and shape of vessels represented, all are identical. There thus appears not the least ground in the evidence of the specimens themselves for the assumption that the Vero pottery pertains to any other than Columbian and immediately pre-Columbian time.[3]

The more comprehensive contribution from the archaeological point of view was made by Dr. George G. MacCurdy, who took

[1] Symposium 1, *Jour. Geol.*, XXV (1917), 41.
[2] *Ibid.*, p. 50.
[3] *Ibid.*, 51.

part in the first conference and symposium. His discussion covers the import of the flint spalls and implements, the bone implements and the pottery. In the course of critical descriptions and observations on these he notes that two of the spalls are identical in material and might well have been chipped from the same flint block. One was found in bed No. 2 and the other in bed No. 3, which he regards as significant and raises the question whether both might not have come from the upper bed through the agency of growing roots or burrowing animals. The spalls were never retouched and were evidently chipped from the parent block near where they were found. As the parent rock is not found in place nearer than the Ocala formation, one hundred miles distant, he thinks the transportation was by human agency. A typical arrowhead of flint with barbs and stem implies the end sought in the chipping and the state of the industry.

To summarize the archaeological evidences of man's antiquity at Vero, one can say that the pottery, bone implements, including fishhooks, boneheads, and flint arrowheads from stratum No. 3 and from the surface of contact between it and the stratum below, all point to a period that might well have continued down to the close of the prehistoric period in Florida. This is also true of the human skeletal remains from the third stratum. On the other hand, of the 25 mammalian species from the second stratum as listed by Dr. Sellards, ten, including *Elephas columbi*, *Mammut americanum*, *Equus leidyi* (?) and *Tapirus haysii* (?), recur in stratum No. 3. Assuming that the stratigraphy is not misleading, the conclusion is either that this particular phase of the Neolithic period in America dates back farther than many had supposed, or else that certain fossil mammals continued to live on in Florida until a comparatively recent date.

The chief interest centers in the second stratum. From it no undoubted stone implements have thus far been reported. Although probably produced through human agency, the flint spalls from this deposit do not differ from those in the deposit above, in one case there being absolute identity of material. While a greater number of bone objects have been found in the third deposit than in the second, bone points of the same type occur in both; neither do these seem to differ as to their chemical state. Potsherds, fairly frequent in stratum No. 3, have not yet been reported from the stratum below. Of the human skeletal remains there does not seem to be any appreciable differentiation between those from the second and those from the third stratum.

There are to be noted then the absence of well-defined stone artifacts and of pottery from the second deposit; the presence of both in the third; the similarity

of the flint chips from the two deposits; the similarity of the bone points in both deposits; and the greater number and variety of bone artifacts, including ornaments in the third deposit. But for the similarity of the flint chips and the bone points, the cultural evidence is very much as one might have been led to expect, assuming of course that the stratigraphy is unmixed and that all specimens have been found *in situ*. On the other hand, in the absence of stratigraphy as a guide, of all the human and cultural remains reported from stratum No. 2, none would seem out of place in stratum No. 3.

. . . . The presence of plant stems, acorn cups, and pieces of wood in the second stratum, although by no means so abundant as in the third stratum, nevertheless give to it an aspect of comparative newness. Some of the leaves in the muck at the base of the third stratum look as if they might have been buried only a few years ago.

From observations made on the spot and from a study of specimens submitted, the writer is of the opinion that for the most part the human skeletal remains, flint chips, and artifacts probably found their way to this meeting-place of waters through the same agencies as did the various animal and plant remains, and that there has been more or less dove-tailing of the two deposits, because of the peculiar location of the site at the junction of two streams coming from opposite directions. If these premises be true, it would be hazardous to attribute any great antiquity to even the oldest human and cultural remains from Vero. It would be more logical to assume that some of the extinct forms found in the second stratum are perhaps derived from an older deposit; that others lived on in that southern clime longer than has hitherto been supposed, and that the presence of the Indian hunter had much to do with the final ringing down of the curtain on the drama of their ultimate extinction.[1]

It will be seen from these summaries that no consensus of opinion was reached or even approached by the several special students who attacked the problem from their own special points of view. The problem, however, was opened up broadly and the lines of profitable future work fairly well indicated, though not specifically stated. The most radical feature disclosed is the very different degrees of confidence reposed in different criteria. As we have already remarked, the really vital question raised by the Vero case is the value of the various criteria that have been in use and continue to be used.

Whatever else may be said, the outcome offered no warrant for the public propagation of any decision or consensus, pro or con, respecting the Pleistocene age of the ancient Vero man.

[1] Symposium 1, *Jour. Geol.*, XXV (1917), 60–62.

The several views relative to the age of the Vero man may be summarized as follows:

From the viewpoint of the State Geologist—Pleistocene.
From the viewpoint of regional geology—opinion withheld.
From the viewpoint of physico-dynamic geology—Mid-Recent.
From the viewpoint of archaeology—Recent.
From the viewpoint of anthropology—Recent.
From the viewpoint of vertebrate paleontology—Early or Middle Pleistocene.
From the viewpoint of paleobotany—Late Pleistocene.
From the viewpoint of invertebrate paleontology—?

STAGE III. A TREND TOWARD ANTAGONISM AND PROPAGANDISM

The preceding co-operative stage was wholesome and fruitful in a gratifying degree, however indecisive. It is less gratifying to note that some signs of a lapse into polemics have recently manifested themselves. While the utmost independence and the highest critical spirit are eminently wholesome, criticisms from personal points of view that take such a form as to place an opposing view at a disadvantage, either from inadequacy or inaccuracy of statement, do not make for wholesome progress. They are not likely to be altogether fair—however well intended—either to readers or to those criticized. If something in that line is regarded as necessary, it is much better given the form of a joint discussion, preferably with exchange of manuscript beforehand. Such a discussion puts both sides before the reader at the same time and on equal footing. If it is felt that an attack must be made, let it be arranged that the defense go with the attack in the spirit of ancient chivalrous combats and in the not less chivalrous spirit of the most approved form of modern polemics.

Partly in association with more or less polemical reviews and partly independent of them, there has appeared also some tendency to propagate preferred views as though they were determinate while yet about half those who have taken part in the inquiry dissent from such views. Unless the fact of such dissent is duly impressed on the reader, he is placed under the disadvantage of partisan influence, and if he is keenly alive to his rights, he is likely to resent this. The varied opinions cited above seem quite clearly

to imply that the time for propagating the Pleistocene or the non-Pleistocene age of man in Florida has not yet come.

But let us pass lightly by this diversive stage and consider whether a rejuvenated effort of the co-operative order may not be made the most worthy successor of the already fruitful second stage.

STAGE IV. FURTHER EFFORTS AT RECONCILIATION AND REVISION

What is the most laudable line of future effort in the light of the disclosures of the preceding conferences? Is it not obviously a concerted effort to evaluate the criteria brought into service, to revise them if found necessary, and to find in an analysis of the case the means of reconciliation of the divergent views? Certainly the true end of endeavor is a concurrent interpretation. To this end should not each advocate stand ready to reshape his view so that it shall be reconcilable, so far as possible, with the evidences that seem to favor some opposing view? We may be sure that Dame Nature has proceeded rationally in the operations at Vero, as everywhere else, and that there really is complete harmony and consistency in the evidences presented.

We beg to make a few observations by way of suggesting further studies in the interest of such revision and reconciliation, but let it be clearly understood that these are but suggestions to deploy the case for additional investigation; they are not proposed solutions.

a) *Suggestions relative to the creek deposits themselves.*—Present processes are fairly clear and quite demonstrable. Recent processes should naturally be next most clear and most demonstrable. May it not be well then to change the order of inquiry by starting where the evidence is best and try to determine first what amount of aggradational work may reasonably be assigned Van Valkenburg's Creek during the Recent Period? The probable minimum length of this, according to the tentative scale given on a previous page, is two hundred centuries. By analyzing its formative processes, it should be possible to reach some approximate notion of the nature of the recent work of Van Valkenburg's Creek and perhaps of its time-relations. The results projected backward

from 1913—when the digging of the canal interrupted the normal work of the creek—for two hundred centuries should give a fairly firm first step in interpreting the actual six feet of creek deposits, if these are to be interpreted as simple aggradational accretions that have escaped reworking. If, on the other hand, reworking has seriously influenced the case, some of the criteria thus far much insisted upon may be brought into question.

Such an inquiry might start from two questions: (1) What is the *normal* thickness of vegetal muck and sand that might reasonably be expected to accumulate in such a situation during the Recent Period? (2) What is the *minimum* amount that can reasonably be thought to satisfy the demands of the case? The first question looks simply to the most rational estimate of work done; the second is influenced by a desire to leave as much as possible of the six feet of the actual deposit for assignment to earlier stages to help reconcile the shallow depth of the deposit with the faunal evidences that imply a great lapse of time. This finds its justification in the fact that a heavy stress is put on interpretation somewhere, and it is in the line of reconciliation for each advocate of a particular view to leave as much leeway as he can consistently for the accommodation of conflicting views. This in the end may be found to be the only way to save his own criteria from serious challenge.

To realize the grave nature of the stress which the case presents in only one of several particulars, let us for the moment suppose that the rate of aggradation on the flood-plain of the creek is no more than one inch per century; the total aggradation of the flood-plain in the two hundred centuries assigned the Recent Period would be more than twice the whole six feet actually shown in the creek sections. The supposition is of course merely illustrative.

Preliminary to any true estimate of an actual deposit of this type, it is necessary to inquire how a creek does its aggrading work on a low gradient plain of its own formation when controlled by a sea-level near at hand. Whatever else is involved—and there is much that cannot be noted here—two quite different classes of work are involved: (1) that done upon the flood-plain which occupies all the creek bottoms not at the time included in the creek

channel; (2) that done in the more limited tract of the stream channel itself. It is essential to note the normal differences between these two forms of deposit and their working relations to one another.

(1) The flood-plain deposits are formed of the residue of whatever grows upon the flood-plain, or may fall upon it in any way, or may be blown upon it by the winds, or may be mired in it when wet and soft, together with whatever may be washed upon it by the stream at the times of freshet or flood. When first spread upon the bottom, the deposits of freshet and flood stages are usually stratified, but they are quite sure to suffer serious disruption by the growth of plants, the tread of animals, and various other surface agencies, so that they very commonly lose their original structure. On bottoms of low gradient in a sandy tract flood-plain deposits are thus likely to be a heterogeneous mixture of vegetal and earthy muck combined with more or less sand, and to embrace as incidentals the hard parts of whatever lives and leaves its relics on the flat surface.

(2) The channel deposits, on the other hand, are usually formed mainly of the normal products carried by the stream along its bottom, notably sand and pebbles, but these are quite sure to be more or less mixed with derivatives from the flood-plain deposits that form the banks of the stream. More or less constantly these muck banks are being undercut and caused to slide into the channel where they are then more or less reworked by the stream. Usually the muck masses are gradually disintegrated and washed onward by the stream, but they may be buried bodily in its sands, thus carrying into these sands whatever the muck masses happen to contain. This content is likely to retain whatever condition it happened to have when in the muck bank.

In addition to these normal processes the stream, at appropriate points here and there, is also engaged in the work of scour-and-fill. This accidents the results and adds its special features to the products of the more uniform channel work.

Now this tripartite work is pre-eminently a mixing process; at the same time it is an assorting process. Each of these two processes is likely to be carried to varying degrees in the mul-

titude of individual cases involved; the mixed product thus commonly shows a wide range of variation. In part the mixing may be very gentle and the hard parts in the muck may show very slight abrasion. The slide of the muck banks into the bed of the creek is often one of the gentlest of moving processes, for the muck lubricates and cushions the sliding mass. The matter enveloped in the muck, however weak it may be, is easily slipped along in its cushion without appreciable strain or abrasion. Muck balls may even be formed and rolled notable distances, carrying in their protecting embrace structures of any degree of fragility until burial shall finally fix them in the stream sands or disintegration shall free them for a cleaner burial in the same sands. The typical channel material in the stricter sense, that is, the material which has been rolled along the stream bed for considerable distances, perhaps from sources beyond the aggradational tract, is normally much more worn, whether it be rock or bones. The several parts of the creek deposit are thus likely to show the effects of very different experiences. Only a critical study of each individual relic is usually sufficient to disclose its special history. Normally there is a very wide variation of conditions ranging from relics that remain almost intact to those which are very much abraded.

Now it is the normal habit of a stream that meanders on a plain of its own formation to shift its channel gradually down-stream by undercutting or eroding its banks preponderantly on the down-stream side. In the course of time the stream thus slowly creeps over its whole flood-plain, and in so doing cuts away and reworks a large part of the flood-plain deposit. As the meanders thus slowly shear their way over new ground, new flood-plain deposits are formed on the ground abandoned by them; thus the flood-plain is rebuilt behind the shearing meander and made ready to be cut away again when the next meander reaches it in its progress down-stream.

Now, as already noted, this shearing process is attended almost inevitably by the special supplementary work of scour-and-fill which bores its holes below the common channel-level at the points of specially forceful or turbulent action. This is particu-

larly characteristic of streams subject to great variations of vigor, as for example streams in regions of alternating dry and wet seasons, as in the Vero case, especially when heavy rains are frequent and even typhoons are occasional. This scour-and-fill action is a special mixing process superposed on the more general ones already sketched.

Now if, in the case in hand, only a foot or so be allowed for the flood-plain deposits in process of growth, and only a foot or so for the normal channel-work, and only a foot or so below that for the deeper scour holes here and there, the vertical range of this active formative and reworking process is too great to be neglected when there are only six feet of deposits altogether to be dealt with. It must be kept in mind that this working combination, now at the top, has in the process of forming the six-foot deposit gradually worked up from the bottom, leaving some portion of its base at successive stages to help build up the lower part of the six feet. This lower part is thus an accumulation of residues from the working combination.

It is therefore necessary to distinguish between the working group at the top—which in the case in hand ceased its formative process in 1913—and the succession of residual deposits below it, these being merely the truncated bases of the formative deposits which the successive meander-shears have left behind. The group in process of formation at the top belongs not so much to the Recent Period as to the current working stage. Setting this aside as merely the record of the work in progress when suspended, how much more is to be added from the rest of the six feet below to make up a reasonable record of the past two hundred centuries, more or less, which, according to our tentative scale, constitute the Recent Period? Will anything less than the two or three feet of the upper layer, No. 3, suffice? Indeed, is that enough?

This method of proceeding from the known to the unknown seems eminently sound and helpful up to this point; here it encounters difficulties and these show its limitations. Theoretically, the several basal accretions left by the successive meander-shears may (1) have some notable thickness, (2) or very little thickness, or (3) even a minus thickness, i.e., there may be loss

of previous gains by the shearing away of more than has been built up since the last shear. Besides this, the time between meander-shears is also more or less uncertain. Just what the actual amount of accretion was in each intershear interval, in the case in hand, can only be determined by an inspection of the accretion layers themselves, if indeed their condition permits this. Even that may not suffice for a positive determination, but it is worthy of trial. Herein lies one of the calls for further investigation before anything purporting to be a final conclusion is put forth.

The method of inquiry here suggested, in spite of its limitations, clearly has these good points: (1) It begins with what is best known and forces a recognition of the formative group of deposits at the surface; (2) it suggests a specific kind of examination of the beds below this working group for specific data; (3) it invites a very critical study of the effects of transfer from one formative deposit to another under conditions whose possibilities are both great and highly varied; (4) it is well suited to throw light on the significant fact that, while only a very small fraction of the total number of bones belonging to any individual skeleton have been found in the deposits in question, implying that the great majority have somehow been carried away or otherwise disposed of, some of these are yet not necessarily much worn; (5) it is well suited to explain why much-worn material and little-worn material occur together; and (6) it makes altogether natural a gradation from the older to the younger content, attended with intermixture.

If the normal mode of formation of creek deposits were the only consideration to be weighed in the matter, the six feet of the deposit might perhaps be so handled in interpretation as to plausibly represent the stream aggradation during all the time between the Aftonian interglacial epoch and the present, though that would seem to be putting a very heavy strain on the probabilities; at least the deposits might not yield any demonstrative evidence to the contrary. So far as it goes, therefore, the method gives a possible basis of reconciliation between the import of the fossils in the basal part of the six feet, interpreted as very

old relatively, and the obvious recency of the upper part. The method is certainly helpful in explaining the crowding into close positional association faunas heretofore regarded as very different in age. To that extent it gives relief to one of the most declared phases of stress that make the case a really notable one.

The one feature in this mode of analysis and interpretation that may not be acceptable to some of the interested students of the case lies in the fact that it not only permits but postulates much transfer from a state of first burial in the flood-plain muck to a state of later burial in the channel sands, and to still further rehandling by the scour-and-fill process. However, this is not that phase of transfer that has been most under discussion in the history of the case. The interpretation suggested does not necessarily involve any transfer from an independent deposit somewhere else to the creek deposits. It is purely negative on this question, which is left to be decided pro or con by its own class of evidence.

A possible episode in the history of the Van Valkenburg's Creek deposits must be suggested briefly to meet one other phase of the deposits. There are specific grounds for thinking that the gradient of the creek may have been steepened, for a time, at some period between that of its early adjustment to the sea as it retired and its adjustment that now obtains at about the same level. Some of the streams, harbors, and inlets in the region seem to occupy drowned valleys, and this has been held by Shaler, Matson, and others to imply that a lower relative level of the sea, to the extent of twenty or thirty feet, obtained for a time. Such relative lowering of the sea-level, if it occurred, would naturally have caused Van Valkenburg's Creek to sink its channel—attended perhaps by a flood-plain of greater or less extent also—into the previous aggradation plain. As the sea-level again arose to its present position, the sunken trench should have been refilled until aggradation would be resumed on the level of the old plain. Such an intervening stage in the drainage seems to harmonize well with the browner color of the lower layer and with the division recognized between the lower and the upper layers, the latter of course being the assigned work of the resumed aggregation on the surface of the old plain.

To fill out a fair recognition of the inevitable mixing processes to which the creek deposits were subject in the course of their accumulation, several incidental activities should be noted, the most important of which perhaps is the overturn of the trees that grew on the bottoms; but this paper would grow tedious if these and other incidental modes of mixing were discussed in detail.

b) Suggestions stimulated by the outer relations of the creek deposits.—Whatever the above suggestions might contribute toward the interpretation of the crowded and mixed association of the fossils and relics in the six feet of creek deposits, if put into service, they would still leave no little apparent conflict of evidence connected with the neighboring and also with the more remote relations of the deposit.

Geologists studying these outer relations, either from the physico-dynamic point of view or from the regional point of view, are confronted with difficulties that naturally cause them to hesitate to believe that the time since the Vero Ridge was formed—which is somewhat greater than the time since the creek deposits began to be formed—can be the record of all that was done here since the Early or Middle Pleistocene. Inevitably then the presence in the beds of extinct mammals that have been regarded as evidence of these early stages raises a serious question as to which class of criteria is the more trustworthy.

Anthropologists naturally hesitate to believe that the Indian type of skeleton could have remained without appreciable modification for forty-five hundred centuries—the minimum date assigned the Aftonian stage in our tentative time-scale—or for any notable part of that long period, and so on these grounds also the question of the relative value of criteria is raised. In this case, interestingly enough, the conflict of evidence takes the form of bone against bone.

The archaeologists are naturally still more hesitant to believe that Indian pottery-making could remain in a static state for the period named or any period measured by hundreds of centuries, not to say thousands of centuries, for when a plastic art is set over against the evolution of biotic species, the presumption of the speedier change lies much in favor of the art.

The paleobotanical evidence has been interpreted as implying a much shorter period than do the mammalian remains between the lower and the upper deposits of the creek series. The general presumption of changeableness, however, has commonly been held to favor the mammals.

Marine paleontology seems to be rather neutral in this war of criteria. The marine layer that underlies the beach ridge in which the creek sank its valley and later began to fill it contains few fossils, if any, of species other than those now living. Using the inherited organic criteria, the age of this layer has usually been placed at or near the end of the Pleistocene Period. It would seem to be a fair accommodation to the general tenor of the various evidences to make the last retreat of the sea from the mainland in the Vero region the beginning of the Recent Period. Such a reference, however, places the *beginning* of the creek deposits *within* the Recent Period. This conforms very well to the apparent requirements of regional geology, of physical geology, of anthropology, and of archaeology. Perhaps paleobotany might be accommodated to it without putting its data under much strain if any at all; but vertebrate paleontology, especially mammalian paleontology, as heretofore understood, would apparently need radical revision. The suggestion here implied, that the extinct mammals may have lived on even into the Recent Period, goes a step farther than the suggestion made at the conferences to the effect that the several vertebrates heretofore only known to occur in Early or Middle Pleistocene beds really lived on in this southern clime until a much later Pleistocene date. Even then it is not necessary to suppose that the older of these extinct mammals were contemporaneous with man, for the two hundred centuries assigned to the Recent Period give room for appreciable differentiation. Obviously this basis of reconciliation throws the burden of revision most heavily on vertebrate paleontology and subordinately on paleobotany.

Those who are thus hypothetically made to bear nearly the whole burden of revision are entitled to trial hypotheses which shall in a like hypothetical way throw the burden of revision on other criteria. The method of multiple working hypotheses, in

its eminent fairness, requires us to make an earnest effort to bring under trial all tenable alternatives, to the end that among these there may be found the one that apportions the task of revision in strict accord with the inherent value of the combined evidence. This in its very nature also covers the question whether or not it is possible to escape all serious revision of criteria by finding some tenable basis of reconciliation not perhaps now recognized.

How such a series of multiple working hypotheses is to be built up from the one we have just suggested is almost obvious, for the one just offered is a rather extreme one and quite suitable to form the end hypothesis nearest us in time. To build out the series from this backward in time, it is merely necessary to push back step by step the assigned place in time of the basal creek deposit and note the degree of strain put on each of the several criteria of interpretation by each step. The measure of total strain in each case—or the best balance of such strain as is unavoidable—forms the index of success of each trial hypothesis.

In studying such a series it will be not only interesting but significant to note that, if we accept the interpretation of the creek deposits already sketched, the extinct vertebrates may be assigned earlier and earlier ages without necessarily bringing any strain at all to bear upon the archaeological and anthropological evidences, for the human relics were buried at horizons so close under the deposits in process of formation when suspended in 1913 that any tenable amount of backward assignment of the content of the lower layers is not likely to carry these relics back beyond the place their own criteria would assign them on independent grounds. The strains that are really brought out by such backward steps in assignments of the date of deposition of the extinct vertebrates or of the plants bear almost solely on the criteria derived from physico-dynamic and regional considerations. The question of the Pleistocene or the non-Pleistocene age of man is thus replaced by the much broader and deeper question, What are the relative worths of the criteria offered by life-extinctions on the one hand, and those offered by physical state, dynamic work done, regional distribution and stratigraphic arrangement, on the other?

In any attempt to rectify the criteria, there is a prerequisite that is strictly indispensable, to wit, the keen recognition that relics buried beneath secondary or tertiary derivatives from the surficial deposits are little better than Mephistophelian in their insidious power to deceive. A relic reported as found beneath twelve feet of gravel or twenty feet of loess by anyone not trained to avoid these Mephistophelian lures is to be held as quite without value until tested; it merely serves as an interrogation point to punctuate the question, Is it worth while to investigate the case?

c) *The deeper and broader issues involved in the Vero case.*—The more profound interest of studious men of science lies in such advances in modes of inquiry, such increases in the trustworthiness of criteria, such larger hospitality to working alternatives, such greater readiness to make trial of these and frankly lay them aside if found wanting; such hospitality to revision, and such larger views of the whole problem as may be drawn out from the case. Let us therefore survey from a more general point of view the main lines along which this problem may be approached with the hope of important light. Foremost among these are: (1) the extinction of biotic species; (2) the introduction of biotic species; (3) the physico-dynamic vestiges; and (4) the regional relations of the formations; the rest must be omitted. The leading criterion of the first is *life gone out;* of the second, *life come in;* of the third, *work done;* and of the fourth, *the deployment of the record.*

(1) In approaching a problem on the first line, it has been customary to bring to bear the times of extinction of the species of faunas and floras that lived in the stages immediately preceding and the ratios of such extinct forms to the living species present. Some advances on the older methods are to be noted. Chief among these is the appeal to causes of extinction as confirmatory evidences. This relates the statistical method to the dynamic method; it helps to co-ordinate the facts of extinction with the work of the agencies that produce extinction. This has chiefly been a co-ordination of faunal changes and glacial climates. Further deployment in this and other directions is much to be desired. As a suggestion in that line, why should not the

northward advance of pathogenic microbes, assignable to the rise of temperature as an interglacial epoch comes on, be quite as plausible a cause of extinction as the southward advance of a cold climate as a glacial epoch comes on? In this particular case may not the advance of the warmth of the early Recent Period have thus been indirectly one of the effective causes of that rather remarkable rate of extinction which seems to be recorded in the six feet of the creek deposits at Vero?

(2) The second line of approach has not been sharply distinguished from the first, nor has it been brought into equal use as a means of discrimination, as the discussion of the Vero case very pointedly shows. Has not the introduction of species, however, resources of discrimination equal to those of extinction, if not indeed greater? In the use of extinctions the inquirer can only start with the imperfect knowledge of earlier faunas and floras. He can only trace these forward to disappearance by means of the inferior record of those earlier times. On the other hand, in the use of the introductions of species, it is possible, by reversing the time-order, to start with the fuller knowledge of the present faunas and floras and trace these backward by the use of the more complete record of recent times. There may thus be brought into use a large amount of data relative to the climatic adaptations of existing species, varieties, and races, and hence by inference, knowledge of the climatic conditions that obtained when these were introduced. By starting with the richer resources of the biologic knowledge of the present and the fuller knowledge of present conditions, there is good reason to hope that before the preceding records grow too obscure, the climatic effects of the last ice invasion even upon southern faunas and floras may be detected, and so the southern fossil records rendered directly comparable to the glacial record.

Now it is highly pertinent to the question at issue to observe that the extinctions and introductions of biotic species, varieties, and races during the last century have been phenomenal in kind and degree. Within the memory of some of us that are older there have been profound changes in the general aspect of the regional faunas and the floras in North America more radical,

perhaps, than were witnessed by the preceding ten generations. That there was a special biologic cause for this only intensifies its importance as a subject of special study. It is such critical events in history that should put us on our guard, for similar critical events probably characterized all the past, as LeConte so wisely urged on our attention.

Co-ordinate with this a like radical change has taken place in the rates of erosion, sedimentation, and the surficial aspects of the land. These climacteric stages in the extinction of species, in the introduction of species, and in surficial evolution furnish stimulating grounds for revision of ideas and a reconstruction of working tenets. They offer a point of departure of most suggestive value.

A very vital phase of this recent physico-dynamico-bio-psychic combination is human art and industry. This becomes a very important additional resource in discrimination. The evolution of the arts and industries is usually far more rapid and much more sensitive to conditions than the evolution of biotic species. It is in like degree a more refined criterion of historical progress.

(3) The third line of approach is an endeavor to find in the record of work done by the chief terrestrial agencies a basis for the natural events that mark off the progress of the ages. These agencies are more or less rhythmical in action and so reach climaxes here and there that serve for dividing lines or points of reference. To a large degree these agencies are the basal causes of the leading events of the geologic record. As such basal causes they are eminently fit for true criteria. Concretely, the physico-dynamic agencies record themselves in changed relations of land and sea, in changes of surface attitude, in changes of soil growth, of denudation, of configuration, and of sedimentation, as also in changes of climate, and of most other environing features that condition life. We have already remarked that glacial invasions and glacial oscillations have already in large measure replaced the older criteria on which are based the divisions of the Pleistocene Period and its separation from the Recent Period. A greatly enlarged use of these newer physico-dynamic criteria is scarcely less than imperative to conclusions that will stand the tests of the future.

(4) The help derivable from the spacial or positional relations of the deposits is most conveniently summed up in the term regional relations, and is best illustrated concretely. Between the Vero location on the very edge of the continent—far to the south—and the glacial formations in middle latitudes, there is a wide stretch of territory covered by Pleistocene and Recent formations, each of which has its place and significance in the recent history of the whole region. Whether we are able to distinguish all these or not, they are there and have their story to tell. These must ultimately be assigned their true place in the natural series that intimately connects the Vero deposits with the glacial formations in the northern states. These fall into four geographic provinces suited for work on the problem in hand. In the working of these provinces, of course, the extinctional, the introductory, and the physico-dynamical methods of inquiry should each play its own appropriate part. The following regional work is definitely indicated:

(*a*) Intensive and correlative work on the marine coastal tracts of the Atlantic and the Gulf. By this connection would be made between the glacial and glacio-natant deposits of the North and the contemporaneous marine deposits of the warm South. In this work the distinctive marine criteria, physical and biotic alike, should be adhered to rigorously and all formations not amply accredited by marine credentials should be left in the waiting list, or placed elsewhere.

(*b*) Inland from this narrow coastal tract, a broad U-shaped tract wraps about the Appalachians with its outer southeastern flank against the sea deposits of the Atlantic and Gulf on the one side and its inner northwestern flank on the glacial deposits of the Ohio Valley on the other, while at the top of the U these tracts abut against the glaciated areas on either side of the mountains. The strategic advantages of working this province as a unit are obvious. The aggradation-degradation deposits on the two flanks of the Appalachians offer special advantages in correlation and in interpretation.

(*c*) The fluvial deposits of the Mississippi Valley, embracing those whose sources lay in the glacial-drainage area of the upper

Mississippi Valley, offer a highly promising line of inquiry in which definite glacial-drainage stages may probably be traced into physical connection with both the terrestrial and the marine deposits of the more southerly regions.

(*d*) The lowland and upland plains west of the Mississippi offer a similarly promising connecting tract between the Keewatin glacial fields and the Gulf coast.

The combined import of careful co-ordinated studies on these promising connective tracts between the fields of warmth and the fields of cold should greatly help in revising and reconciling the discordant interpretations so notably brought out—so fortunately brought out, shall we say,—by the singularly suggestive deposits at Vero.

INEQUALITIES OF SEDIMENTATION[1]

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CONTENTS

INTRODUCTION
CLASTIC DEPOSITS
Observations on the Great Lakes
Littoral marine deposits
Current work in deep water
Shifting of deposits
Relative aridity
Rôle of vegetation in estuaries
Periodic and cataclysmic variations
ORGANIC AND BIOCHEMICAL DEPOSITS
Limestones of biochemical origin
Coral reefs
Lithification
Variability of Molluscan contribution
Bone beds
Displacement of ocean currents
Barren areas
Seasonal variation
CONCLUSIONS

INTRODUCTION

Most of the earlier discussions touching the subject of sedimentation leave in the mind of the reader the impression that water-laid sediments other than delta deposits accumulate over very wide areas at a nearly uniform rate. Leaving out of consideration delta and estuarine sediments whose relatively rapid accumulation is of course universally recognized, variability or contrast in rates of deposit between different areas and between different periods in the same area rather than uniformity appears to the writer to be the dominant feature characterizing sedimentation. In both its time and space relations sedimentation is highly variable.

[1] Published with the permission of the director of the Geological Survey of Canada.

It is the purpose of the present paper to point out some of the factors which make for periodic variability in the rate of deposition and to cite some examples from existing lakes and seas to illustrate the sharp contrasts in the rate at which sediments accumulate at different points near the same coast line.

Some familiarity with the mobility of wind-formed deposits is unavoidable, but with the far greater mobility of water-laid deposits we have a comparatively slight acquaintance. We are apt to think of clastic deposits which have once come to rest on sea or lake bottom as permanently fixed. That such materials lose nearly half their weight in water and in a corresponding degree their tendency to "stay put" is apt to be forgotten in considering the history of geological formations. Removal or migration of parts or the whole of an unconsolidated formation may occur much more rapidly below than above sea level. The buoyancy of water, together with the general absence of the fixing influence of vegetation, gives to unconsolidated aqueous deposits under the combined influence of waves and currents a far greater degree of mobility and instability than subaërial deposits possess.

CLASTIC DEPOSITS

Observations on the Great Lakes.—Previous to human interference sand dunes represent in a moist climate an established equilibrium between the forces of the winds and the waves and the stabilizing influence of vegetation. The slightest interference by man with the vegetable covering of a sand hill country which is usually found in temperate climates may, however, start the dunes of a whole region traveling. It is said that the highest dune of Friesland owes its origin to the destruction of a single oak. Water-laid deposits represent a similar balance of forces in which water currents replace air currents.

The deposits of the foreshore represent the innermost zone of sedimentation. They may be examined in part at least from the vantage ground of the shore. Because of their comparative accessibility to observation the deposits of bars, tickles, and spits illustrate well the irregular and highly localized character of the inshore deposits.

The shores of the Great Lakes afford examples of these massed aggregations of sand and gravel flanked by extended areas of shoreline along which little or no deposition of sediment occurs. The south shore of Lake Erie east of Sandusky is nearly everywhere composed of Devonian shales or glacial till, the wave and current action being destructive instead of constructive. At Erie, Pennsylvania, however accretion dominates the elsewhere prevailing erosion and a long, broad spit has been built into the lake inclosing Erie harbor.

On the Canadian shore of Lake Ontario at Toronto, in sharp contrast with the bare rock bottom frequently found near the shore of Prince Edward county, there is a sand spit building out into water nearly 200 feet deep. In the Burlington bar which extends from the north to the south shore of Lake Ontario five miles from the western end of the lake we have in the maximum depth of the enclosed lagoon, 80 feet, an approximate measure of the total thickness of the bar deposit which has been built up during the relatively short life of this lake. Convincing evidence that bars form even far more rapidly than such a figure would suggest is furnished by the observations of Russell[1] on a bar at Round Island in Lake Huron. Two photographs by Russell taken ten years apart show that the bar increased 1000 feet in length during this interval. Observation of the movement of littoral drift along the shore of Lake Ontario affords equally clear evidence of the rapid movement of very coarse sediments and shingle. In the vicinity of Oakville the littoral drift is westward. Two piers built out into the lake at this point on opposite sides of a river mouth to protect navigation act as groins. Nothing accumulates on the beach behind the west pier, thus showing that there is no movement of material toward the east. Alongside the east pier, however, the beach is growing out into the lake and during periods of rough weather the westerly moving shingle nearly overwhelms the base of the pier and the building near it.

In the Great Lakes the vigorous action of currents is by no means confined to the immediate vicinity of the shoreline. A

[1] Russell, "A Geological Reconnaissance along the North Shore of Lakes Huron and Michigan," *Geol. Surv. of Michigan* (1905), p. 104, Pl. 15.

curious feature of their behavior is its capricious character, reminding one of fitful gusts of wind on a stormy day. A single excerpt from the notes of Mr. E. J. Whittaker on the behavior of currents in Lake Erie 2 miles south of Point Pelee will illustrate this.

> Water depth 18–20 feet; float at depth of 15 feet; average current rate 1.91 miles per hour. Current here alternately slackened and quickened. Off this point I also got a good illustration of this with a small motorboat while soundings were being taken by Philp's men. The motorboat running at perhaps 2½–3 miles per hour for intervals of three minutes at a time was unable to make any headway at all. The current then suddenly slackening, the boat would fairly bound forward as though released from a chain. This was the most notable instance of a strong varying current. Moreover here the current changed its direction completely inside of 45 minutes, first being a strong easterly current and at the conclusion of observation being from the west.

In direction the lake currents are variable but only within certain well defined limits. At Southwest Shoal light-ship, a short distance from the station referred to above, current observations which continued over a period of two months during the summer of 1918 showed easterly and westerly currents with about equal frequency but no other direction is represented. Another Lake Erie station which was occupied for some weeks shows only southerly currents. It is therefore certain that the work accomplished by lake currents is not of a haphazard character and that some of their general results in sedimentation can be inferred with certainty when a sufficient amount of data on their behavior becomes available.

Littoral marine deposits.—The movement of sediments along the shores and over the bottoms of the Great Lakes, although it is considerable, is far outclassed in volume by the material which is constantly passing over the littoral zone of many sea coasts. The construction of harbor defenses against the sea sometimes affords surprising evidence concerning the volume of sediments which moves along the sea bottom in front of the foreshore. Instructive evidence concerning the great volume of such traveling sediments on some parts of the sea shore is furnished by the history of the Madras Harbor in India.

> The Indian Government in 1876 determined to construct an enclosed harbour at Madras. Careful observations were made of the volume of sand travel, and it was estimated that it would take 180 years for the travelling

sand to fill a triangular area between the coast line and a breakwater running out 1,200 yards from the shore. No sooner, however, were the works commenced than it became obvious that the above estimate of sand travel was completely unreliable. The wave-borne sand travelling up from the south was about sixty times greater in volume than the corresponding amount brought down by the northeast monsoons. The original estimate of sand in motion was 243,000 tons per annum; a second estimate in 1904 was 550,000 tons per annum. The accumulation at the present time shows that about 1,000,000 tons per annum travel along the coast line. Low-water line between 1876 and 1912 has crept seawards for a distance of 2,500 feet. In 1881 a terrific cyclone wrecked the harbour works then nearly completed but a somewhat similarly outlined harbour has since been carried out on altered lines. For a distance of more than 3 miles severe erosion has taken place on the north side of the harbour due to the arrest of the normal volume of travelling sand, and whole towns and villages have thus been swept away. This experience is an extreme instance of the action which goes on in a greater or less degree at every headland, river-mouth or solid projection from a foreshore into the sea.[1]

It may be noted here that the migration of clastic materials in the littoral zone is not confined to the finer products of erosion but comprises much coarse material and even heavy blocks of stone.

Rollers bring in shingle and sometimes large masses of rock from deep water. It frequently happens that, after a severe gale in the channel, boulders weighing several hundredweight will be found strewn along the strand. These are mostly weed-covered. The growth of weed evidences the fact that the action of the waves has reached sea depths normally tranquil. In exposed portions of the coast line of Scotland boulders upwards of 2 tons in weight are similarly thrown up after storms and their occurrence on these spots is so much a matter of course that they go by the name of "travellers." Their buoyancy being increased by the crop of seaweed they carry, they are pushed along the sea bed under the impulsion of the deep-water rollers. As an instance of deep-sea wave action may be cited the fact that concrete blocks at Peterhead harbour weighing 47 tons were forced out of position at a depth of 40 feet below low water.[2]

The English Channel is an area over much of which clastic sediments pass without stopping to build up formations. The detailed explorations of the bottom of the English channel made by

[1] A. E. Carey, "The Sanding up of Tidal Harbours," *Proc. Inst. C.E.*, CLVI (1903–4), 1–90; A. E. Carey and F. W. Oliver, *Tidal Lands*. Blackie & Sons, Ltd., (1918), pp. 144–45.

[2] *Op. cit.*, p. 150.

Science & Industry
Department

French engineers[1] many years ago in connection with the proposed submarine railway tunnel showed the sea floor to be free of unconsolidated or recent deposits from the French to the English coast between Dover and Calais. Because of the prevailing westerly and southwesterly winds the normal littoral drift in the English channel is eastward, so that most of the detrital material which passes through it doubtless comes to rest in the North Sea. Much of the coarse materials stop on the Dogger bank. This bank which is bounded by the 20-fathom line and covered by quartz sand is comparatively free from the finer silt which occurs in the deeper parts around it.[2] The sand and mud formations now forming in the North Sea represent the time interval since the submergence of the North Sea and English Channel area. These deposits probably thin out gradually toward the Channel where this considerable time interval is entirely unrepresented by any sediments. This it will be noted gives a relationship of areas where a formation is absent, relatively thin, and comparatively thick, which when met with in the consolidated rocks is generally ascribed to overlap. The Potsdam sandstone of New York and Ontario affords a comparable example. It is absent in the upper Ottawa valley, less than 100 feet thick over much of the southeastern Ontario but reaches a thickness of several hundred feet in eastern New York. Its progressively decreasing thickness from Lake Champlain to Ottawa is generally ascribed to overlap.

In the enclosed Arctic seas west of Greenland McMillan reported currents with a usual velocity of about 2 miles an hour.[3] In the same region Low has made the important observation that

> With bodies of water having a general north-south trend the current will flow north on the east side and south on the west side while in east and west bodies the direction will be west on the north side and east on the south side.[4] On the Greenland side a southerly current comparatively free of ice allows the

[1] A. Strahan, "The English Channel," *Nature*, XXV (1882), 463–67; *Lond. Geog. Jour.*, XXXI, 420.

[2] *Royal Comm. on Coast Erosion and Afforestation*, III (1911), Part 1, p. 9.

[3] J. G. McMillan, *Report of the Cruise of the Dominion Government Steamer Arctic in Northern Waters, etc., in 1908-9*, p. 469.

[4] A. P. Low, *Cruise of the Neptune* (1906), p. 289. Canadian Government.

open sea to raise the general temperature while on the Elsemere side the Arctic current with its continuous stream of ice blocks the bays and does not allow the open water to ameliorate the cold of the ice covered lands.

It is evident that currents trending in opposite directions on opposite sides of narrow sea ways will tend to develop marked contrasts in the kind as well as in the amount of sediments which they distribute in comparatively limited areas.

In Chesapeake bay Hunter has shown that both erosion and accretion are contemporaneously in progress in adjacent parts of the bay. He finds that in the area studied, "The areas subjected to erosion aggregate 35 square miles and those subjected to sedimentation 9 square miles, making an excess of 26 square miles eroded."[1]

In the Bay of Fundy the processes of deposition and scour are both active as Matthew[2] has pointed out. His statement is summarized as follows:

In the Bay of Fundy the velocity of the tide varies from two to three knots at its mouth to seven or eight knots in the Parrsboro passage near its head. Near its mouth, on the New Brunswick side, a portion of the bay is separated by a chain of islands, and is called Passamaquoddy Bay. . . . . The rush of the tide through these passes causes a roaring sound which may be heard for many miles, and the whirlpools in them are strong enough to upset boats and careen large vessels; both channels are full of deep holes, ledges, and pointed rocks. At Quoddy River the tide passes over barriers having only fifteen fathoms of water at low tide, yet within owing to the erosion of the tidal currents, there is fifty fathoms in the narrowest and straightest part, and thirty fathoms where it merges into the shallower water of Passamaquoddy Bay. . . . . Up in Chignecto Passage also off Cape Enrage, there is a trough scooped. out by the tide, which is outlined by the thirty, twenty-five, and twenty-fathom contour lines. . . . . But it is in the eastern arm of the Bay of Fundy—Minas Channel and Basin—that the scouring action of the tide is most conspicuous. . . . . The violence of the current in the deep troughs of Minas Channel and Basin occasions the roughest bottom observable anywhere in the bay, for at these points rock and gravel compose the bottom over which the tidal waters run. . . . . The north side of the Bay of Fundy having the slower run of tide, and being that along which the principal rivers enter, has in parts a muddy

[1] J. F. Hunter, "Erosion and Sedimentation in Chesapeake Bay around the Mouth of Choptank River," *U. S. Geol. Surv. Prof. Paper 90B* (1914), p. 14.

[2] G. F. Mathew, "Report on the Superficial Geology of Southern New Brunswick," *Can. Geol. Surv. Rept. of Prog. for 1877–78* (1879), pp. 18EE–22EE.

bottom. The only mud-bank of considerable volume is that formed by the sediment which the St. John River carried to the sea. It begins at the harbor of St. John and extends westward along the coast as far as the small islands called The Wolves, its outer limit coinciding nearly with the fifty fathom line. . . . . As a rule where the movement of the current exceeds one and a half knots mud is not deposited on the bottom of the bay.

Current work in deep water.—It must be pointed out that non-deposition and scour is not confined to shallow and narrow sea ways. Ocean currents are known to sweep the sea floor at considerable depths and at considerable distances from land. At the head of the Bay of Bengal the great delta deposits of the Ganges and Brahmaputra rivers are interrupted by a deep channel called the "Swatch of no ground" which is kept open presumably by some acceleration of the tidal currents. This channel which has a depth of 200 to 300 fathoms terminates abruptly on the west side in water only 5 to 10 fathoms deep.[1] Thus we have in the midst of an area in front of the mouths of the two greatest rivers of India where sedimentation proceeds with great rapidity a belt of sea bottom where deposition is supplanted by scour.

Off the west coast of Scotland tidal currents of great strength are known at some points to sweep the bottom at a depth of nearly 100 fathoms. Between Glas Island and Sgeir-i-Noe in the Little Minch off the west coast of Scotland the flood-stream often takes the buoys of the long lines down "and it is a remarkable circumstance, indicative of the great depth of the tidal-stream here, that the buoys though anchored in 70 or 80 fathoms are taken completely to the bottom; starfish and other marine animals being found attached to them."[2]

The laying of the transatlantic cables brought to light evidence of powerful currents at unexpected depths.

Perhaps the most marked experience we have had of currents at great depths was in the case of the Falmouth cable near Giberaltar. At 500 fathoms the wire was ground like the edge of a razor and we had to abandon it and lay a cable well inshore. Captain Nares, of the surveying ship *Nemesis*, I

[1] James Ferguson, *Quart. Jour. Geol. Soc.*, XIX (London, 1863).

[2] *Sailing Directions for the West Coast and Islands of Scotland from the Mull of Cantyre to Cape Wrath*, p. 119.

think, with tangles could get no specimen of the bottom whatever, and he thinks he got sufficient evidence to prove the existence of a perfect swirl at that depth. . . . .[1]

South of the Azores, Hjort found considerable tidal currents down as deep as 800 metres.[2] Reade[3] has pointed out the evidence which certain relatively deep soundings afford regarding the irregularity of deposition. "In the Little Minch there is a 'deep' between the Isle of Skye and North Uist with a sounding of 107 fathoms, 'rock' the surrounding bottom with soundings from 50 to 90 fathoms being shells, sand, or mud."

Between the island of Rum and the island of Barra there are a good many soundings showing rock, which are deeper than others in the vicinity which have muddy bottoms.

If we find hard ground we know that there must be something to prevent the accumulation of sediment. Now the only thing that prevents the accumulation of sediment is a current, and one help that telegraph soundings have thus given to geographical science as an indication that tidal currents exist even at very great depths in the open ocean.[4]

Most if not all deep-sea naturalists have noted even in the deeper parts of the continental shelf evidences of current action. Verrill has pointed out in the following quotation how such currents over certain areas southeast of New England have prevented the formation of argillaceous sediments.

The prevalence of fine sand, along the Gulf-stream slope in this region, and the remarkable absence of actual mud or clay deposits indicate that there is here at the bottom, sufficient current to prevent for the most part the deposition of fine argillaceous sediments over the upper portion of the slope, in 65 to 150 fathoms. Such materials are probably carried along till they eventually sink into the greater depths nearer the base of the slope or beyond, in the ocean basin itself where the currents are less active. It is probable

[1] Quoted by T. Mellard Reade, in "The North Atlantic as a Geological Basin," Presidential Address, Liverpool Geol. Soc. Session, 1885–86.

[2] Johan Hjort, "The Michael Sars North Atlantic Deep-Sea Expedition 1910," *Geog. Jour.*, XXXVII, 349–77.

[3] T. Mellard Reade, "Tidal Action as an Agent of Geological Change," *Philosophical Mag.*, XXV (1888), Series 5, p. 514.

[4] *Ibid.*, p. 514.

that such a movement of the water may be partly due to tidal currents, as well as to the actual northward flow of the Gulf Stream which is here slow, even at the surface.[1]

Charles Darwin long ago discussed some of the striking examples of inequalities in sedimentation which occur in the Red Sea and in the West Indies. The extent to which the significance of his very important observations appears to have been neglected by geologists may justify the following quotations from them.

The area of deposition seems less intimately connected with the debouchment of the great rivers than with the course of the sea-currents; as is evident from the vast extension of the banks from the promontories of Yucutan and Mosquito. . . . .

Besides the coast-banks there are many of various dimensions which stand quite isolated; these closely resemble each other; they lie from 2 or 3 to 20 or 30 fathoms under water and are composed of sand, sometimes firmly agglutinated with little or no coral; their surfaces are smooth and nearly level, shelving only to the amount of a few fathoms very gradually all round towards their edges, where they plunge abruptly into the unfathomable sea. This steep inclination of their sides which is likewise characteristic of the coast banks is very remarkable: I may give as an instance, the Misteriosa Bank on the edges of which the soundings change in 250 fathoms horizontal distance from 11 to 210 fathoms; off the northern point of the bank of Old Providence in 200 fathoms horizontal distance the change is from 10 to 152 fathoms; off the Great Bahama Bank in 160 fathoms horizontal distance the inclination is in many places from 10 fathoms to no bottom with 190 fathoms. On coasts in all parts of the world where sediment is accumulating something of this kind may be observed; the banks shelve very gently far out to sea and then terminate abruptly. . . . . I may observe, although the remark is here irrelevant that geologists should be cautious in concluding that all the outliers of any formation have once been connected together for we here see that deposits, doubtless of exactly the same nature, may be deposited with large valley-like spaces between them. . . . . [2]

I may instance the great banks of sediment within the West Indian Archipelago, which terminate in submarine slopes, inclined at angles of between 30 and 40 degrees, and sometimes even at more than 40 degrees. . . . . That in some cases, the sea instead of spreading out sediment in a uniform sheet, heaps it round submarine rocks and islands it is hardly possible to doubt, after having examined the charts of the West Indies.[3]

[1] Verrill, "Marine Faunas off New England Coast," *A.J.S.*, XXIV (1882), 449.

[2] Charles Darwin, *Geological Observations* (1851), Part I, pp. 196–97.

[3] *Ibid.*, Part II, pp. 133–37.

In the light of the abundant evidence it is hardly possible to doubt that currents play a great rôle in localizing the accumulation of sediments. In the words of the late Clement Reid:

> There is a general impression that marine action cannot go on much below low water; but this is altogether a mistake. Tidal scour may go on at any depth, provided the current is confined to a narrow channel, so as to obtain the requisite velocity. If in addition there is a to-and-fro motion such as that caused by the Atlantic swell at depths of at least 50 fathoms, the actual current required to remove even coarse sand need only be very gentle. The oscillation in one direction may not reach the critical velocity; in the other this velocity may just be exceeded; the movement, therefore, of the sand grains may always be in one direction especially if the courses taken by the ebb and flood tides do not coincide, or their velocities differ.[1]

The relative importance in sedimentation of the rôle of wave action which is constantly before our eyes is apt to be overestimated. Current action which even when most vigorous is seldom visibly in evidence is apt on the other hand to be unduly minimized.

Shifting of deposits.—The power of currents to transport sediments is nearly everywhere subject to periodic variations resulting from the influence of storms. In some regions there appears also to be a seasonal acceleration and retardation of tidal currents. Branner was told by a pilot on the Brazilian coast "That the currents inside of the Abrolhos and Parcel das Peredes reefs set strongest to the southwest in May, June, and July; that they run in the same direction at other times of the year, but not so strongly." Such variations in current velocity must result frequently in considerable deposits being laid down and subsequently removed by the same current.

A change in depth of wave base and in the courses of currents resulting from the elevation or depression of a coast line may result in shifting the position of an entire formation. As Vaughan Cornish[2] states, "A very small disturbance of conditions if long continued can shift the largest shoal. Such a disturbance is the recession of the coast line. It is probable that a shoal off the coasts

[1] Reid, *Submerged Forests* (New York: G. P. Putnam's Sons, 1913), p. 85.

[2] Cornish, "On Sea Beaches and Sand Banks," *Geog. Jour.*, XI (1898), 641.

of our eastern counties [England] tends to travel at the same rate as the coast is cut back."

Observation of surface currents alone will afford no positive evidence concerning the direction in which bottom formations are growing, nor their source. On the shoal east of Gorda bank the direction of the flow is nearly at right angles to the surface current. North of Barbados 60 miles Pilsbury[1] found at different levels between the surface and 200 fathoms, currents flowing in three different directions, simultaneously the lower at right angles to the surface.

Relative aridity.—The average annual loss by erosion is 95 tons for every square mile of the United States, excluding the Great Basin, according to an estimate published by the U.S. Geological Survey. The enormous volume of sediment which this contribution from nearly 3,000,000 square miles yields is distributed around the continental shelf of North America with a degree of irregularity corresponding to a number of variable factors. Among these factors are the variability in the rate of rainfall, location of river mouths, the direction and velocity of air currents, and the strength and direction of tidal currents. The interplay of all these and of various other factors will doubtless result in building on parts of the continental shelf deposits of great thickness and very considerable extent. Over other extensive areas nothing at all will be left by the ocean currents, and scour may result. The general result may be an irregularity of deposition as great as that which characterizes wind-blown deposits.

The comparatively small volume of clastics which an arid region like western Australia could furnish to its extended littoral zone would result in a minimum rate of deposition which would probably be much lower than that of any other continental coast line. This vast region which is essentially a desert coast line of about 3,500 miles has not a single river of any size. The so-called rivers are mostly insignificant streams many of which are nearly dry unless during the rainy season.[2]

[1] Pilsbury, "The Gulf Stream; Methods of the Investigations and Results of the Research," *Rept. U.S. Coast and Geol. Survey* (1890), Appendix 10, p. 570.

[2] Henry M. Cadell, "Some Geological Features of the Coast of Western Australia," *Edinburgh Geol. Soc. Trans.*, VIII (1899), 174.

If with the littoral zone of western Australia such an area as the Bay of Bengal is contrasted, the enormous difference in the volume of clastic sediments which comes to rest on different parts of the sea bottom is clearly seen. The upper part of the Bay of Bengal receives the drainage from the southern slopes of the Himalaya Mountains where in places the rainfall amounts to 472 inches or nearly 40 feet per annum.[1]

Rôle of vegetation in estuaries.—Closely related to the relative aridity of the sea coast in different parts of the world is the variable rate at which sedimentation on different coasts transforms shallow estuaries into marshes and eventually into dry land. When sedimentation has developed to the stage of shifting sand banks in an estuary, vegetation becomes the chief factor in fixing these and in extending land conditions. In an arid climate the virtual absence of this factor may cause the last stages of filling to proceed with extreme slowness while in a moist climate they will develop with relative rapidity. The rôle of vegetation as a factor in late stages of sedimentation is well illustrated in Professor Oliver's study of the plant life of a salt marsh in Brittany called the Bouche d'Erquy.

> Sand litters the beach, and in part is blown by the winds to form the barrier of sand dunes. Another part is brought into the estuary and is driven hither and thither by every tide. So restless are the shifting sands in the lower part of the estuary that plants cannot gain a footing, though seed be scattered far and wide. Higher up as we saw stability has been reached, and the ground is held by a turf of halophytes, and half way up the estuary where the bare and covered parts adjoin, the restless sands are tamed and bound. The transition from the fixed marsh to the mobile sand is a gradual one. The continuous carpet of the former gives place to scattered hummocks or tussocks of *Obione portulacoides* and the perennial *Salicornia radicans*. Beyond this the *Obione* dies out and the *Salicornia radicans* carries on its colonizing work alone. This it does by throwing out each year its seeds which germinate on the treacherous sand. . . . . In some places the pioneers are advancing at a rate of 10 feet a year, elsewhere less rapidly; whilst in spots where the sand is very mobile they seem perfectly stationary but the local conditions are always changing and the most unpromising surroundings may give place at any time to such as favour a rapid advance. A rough estimate based on the rate of progress noted during the last three years and on the assumption that this rate will

[1] G. T. Bonney, *The Structure of the Earth*, p. 40.

not be checked would indicate that two hundred to two hundred and fifty years must elapse before the whole estuary is carpeted with halophytes.[1]

Periodic and cataclysmic variations.—Variations in sedimentation which correlate with a time factor may be referred to two classes: (1) periodic or seasonal, and (2) those without any definite period of recurrence which may be termed cataclysmic. To the first class belong the differences in the quantity of sediment which is deposited on a delta front during the spring flood period and the winter season. Such differences may be recorded in banding or lamination similar to those which Sayles[2] has interpreted as of seasonal origin in certain aqueoglacial deposits. To the cataclysmic order of variability belong the profound alterations in coast lines and in shifting of the sediments near them which result from phenomenal tides, great storms, and tidal waves. The Bay of Fundy has furnished a good example of tides of extraordinary height in the Saxby tide, which accompanied the heavy Saxby gale of October 5, 1869.[3] The destruction of the city of Galveston a few years ago, resulting from the piling up of sea water on a low shore by a great storm, illustrates well the profoundly destructive character of storms of maximum intensity which may recur only at intervals of one or more centuries. The folklore of many races affords evidences of such phenomenal disturbances in the normal relations of land and sea in the form of legends regarding a universal deluge.

The rise of the sea to an unusual height resulting from tempests of exceptional violence over low-lying lands which occurs at widely separated intervals along some coasts has frequently resulted in sudden and most comprehensive alterations of the physical geography. The piling up of the water of the North Sea on the north coast of Holland has repeatedly resulted in submergence and great disaster to extensive areas in Holland within the historical period. It is estimated that 2,336 square miles[4] have been swallowed by the

[1] F. W. Oliver, "An Experiment in Co-operative Fieldwork in Botany," *The Southeastern Naturalist* (England, 1907), p. 41.

[2] R. W. Sayles, "Seasonal Deposition in Aqueoglacial Sediments," *Mem. Mus. Comp. Zoöl.*, XLVII (1919), 1–63, pls. 1–16.

[3] Robert Chalmers, *Can. Geol. Surv. Ann. Rept.*, Vol. 7, n.s., 1894 (1896).

[4] E. Reclus, *The Earth and Its Inhabitants*, III, 462.

sea in Holland since the thirteenth century. One of the most remarkable of these changes produced the Zuyder Zee. In the thirteenth century

> the low lands along the Vlie, often threatened, at last sank in the waves. The German Ocean rolled in upon the inland lake of Flevo. The stormy Zuyder Zee began its existence by engulfing thousands of Frisian villages, with all their population and by spreading a chasm between kindred peoples.[1]

The political as well as the geographical continuity of the land was obliterated by this tremendous deluge. Another of these great inundations occurred in 1570.

> A continued and violent gale from the northwest had long been sweeping the Atlantic waters into the North Sea, and had now piled them upon the fragile coasts of the provinces. The dykes, tasked beyond their strength, burst in every direction. The cities of Flanders to a considerable distance inland were suddenly invaded by the waters of the ocean.[2]

ORGANIC AND BIOCHEMICAL DEPOSITS

Limestone of biochemical origin.—In the case of non-clastic sediments variability in the rate of accumulation in different areas is probably as pronounced as it is in clastic sediments. There is little available data concerning the rate at which limestone sediments accumulate. But it is probable that a seasonal factor may become recognizable. The formation of limestones of biochemical origin is confined to rather definite geographical areas. Although sea water generally contains about 2,000,000 tons of calcium to the cubic mile[3] it is being extracted and built into rock formations within the confines of the tropics and subtropics in far greater quantities than elsewhere. The development of coral reefs, the formation of calcareous deposits by denitrifying bacteria and the lithification of shore deposits are the principal elements in the inequality of the distribution of calcareous sediments. The limitation of the action of each of these agencies to wide belts on

[1] J. L. Motley, *The Rise of the Dutch Republic*, Historical Introduction VI, Vol. I, p. 35 (London, 1913).

[2] *Op. cit.*, Vol. II, Part III, chap. v, pp. 285–87.

[3] John Murray, *Nature*, XXXIX (1889), 426.

either side of the equator strongly tends to confine the formation of considerable deposits of limestone to the tropical and subtropical seas.

Much has been accomplished in recent years toward delimiting the factors responsible for the areal limitations on limestone formations. The more recent work which has been done on the biochemical factors chiefly concerned in the formation of limestone has been summarized by Vaughan.[1]

In the Florida-Bahama region occur vast areas of chalky mud. These give place to non-calcareous sediments farther north. Dr. Vaughan's work on the Florida coast has shown that the bottom deposits now forming inside the Florida Keys varies from quartz sand to nearly pure calcareous ooze. He writes:

> Silica is abundant in the form of sand in the northern portion of Biscayne Bay, it becomes rarer toward the southwest and is present in small quantities as far as Big Pine Key. Toward the southwest as the silicious material becomes rarer, calcium carbonate becomes progressively more abundant, occurring as a flocculent sediment or ooze over practically the entire region from the lower portion of Biscayne Bay to the Gulf end of Florida Bay.[2]

The important discovery by the late Dr. G. H. Drew[3] of the part played by marine bacteria in producing chemical conditions favorable to the precipitation of calcium carbonate gave the first clue to the mode of origin of these incipient limestones of the Florida Keys. The environment considered especially favorable for these denitrifying bacteria includes a tropical or subtropical climate with "drainage into the sea of a well-wooded country composed of calcareous rock and the soluble organic calcium salts would be precipitated as calcium carbonate by the action of the bacteria."[4]

Coral reefs.—The contribution of corals to limestone formation is made chiefly in the form of fringing reefs some of which, like the Great Barrier reef of Australia, are several hundred miles in length.

[1] T. W. Vaughan, "Chemical and Organic Deposits of the Sea," *Bull. Geol. Soc. Amer.*, XXVIII (1917), 933–44.

[2] T. W. Vaughan, "A Contribution to the Geological History of the Floridan Plateau," *Carnegie Inst. of Washington, Pub. 133* (1910), p. 119.

[3] G. H. Drew, *Year Book Carnegie Inst. No. 10* (1911), p. 125.

[4] *Ibid.*, p. 139.

They occur also in detached masses called *chapeirões* on the coast of Brazil which Hartt described as follows:

> Corals grow over the bottom in small patches in the open sea, and without spreading much often rise to a height of forty to fifty or more feet like towers, and sometimes attain a level of low water, forming what are called on the Brazilian coast *chapeirões*. At the top these are usually very irregular and sometimes spread out like mushrooms, or as the fishermen say like umbrellas. Some of these *chapeirões* are only a few feet in diameter.[1]

Lithification.—Lithification of unconsolidated materials is a potent factor in permanently fixing on the seashore and bottom deposits of shifting sands, gravel, and other materials. Lithification of loose sediments by the deposition of Ca_2Co_3 is subject in a general way to latitude control. On the Atlantic coasts it is a relatively unimportant factor north of Florida on the American side and is seldom reported north of France on the European coast. The action of this factor on the coasts where it is common and important is highly irregular and as yet imperfectly understood. On the northeast coast of Brazil it has produced the curious wall-like reefs bordering the shoreline which have been described in detail by Branner.[2] Similar structures occur in the Levant which have been described by Lartel,[3] Hull,[4] and others. Beaufort[5] shows that the ancient port of Pompeiopolis in Asia Minor has been filled with dune sands which have become solidified on the beach of the port. This case, Branner notes, shows that the lithification has occurred within historical times.

At the island of Ascension Darwin found on the sea beaches immense accumulations of small well-rounded particles of shells and corals. At the depth of a few feet these were found cemented together into stone. These calcareous masses had been under

[1] C. F. Hartt, *Geology and Physical Geography of Brazil* (Boston, 1870), pp. 174–200.

[2] J. C. Branner, "The Stone Reefs of Brazil," *Bull. Mus. Comp. Zoöl.*, XLIV (1904), 1–285, pls. 1–83C.

[3] L. Lartel, *Exploration géologique de la Mer Morte de la Palestine* (Paris, 1887), p. 199.

[4] Edward Hull, *Mount Seir, Sinai, and Western Palestine* (London, 1889), p. 148.

[5] Francis Beaufort, *Karamania or a Brief Description of the South Coast of Asia Minor* (2d ed.; London, 1818), p. 249.

the observation of Lieutenant Evans for six years, who reported that there was an annual addition to them sometimes amounting to half an inch in thickness which began to deposit in October with the change in direction of the prevailing currents and which was later in the year in part re-dissolved by the waves.[1] This resolution of the calcium carbonate clearly indicates a seasonal factor in the formations of some limestones, deposition proceeding during only a portion of the year.

Variability of the Molluscan contribution.—The relative abundance of marine life on different parts of the sea bottom must be an important factor in the variation in rate of limestone accumulation in different areas. The general tendency of animal life to flourish best in shallow water is a well established fact. "Very many observations point to the conclusion that the density of life, both fishes and invertebrates, is greater on the sea bottom in close proximity to the land than in deeper waters farther out to sea. It is in such inshore waters that one finds the greatest wealth of animal life."[2] On the beach itself certain forms of marine life flourish in extraordinary abundance. At Fleshmick on the Isle of Man 2,940 individuals of *Balanaus balanoides* have been counted on one square foot of sea shore.[3]

In fresh-water lakes molluscan life is practically limited to depths less than 25 feet. Although a few fresh-water species have a bathymetric range much greater than this the contribution of such species to the calcareous element of lacustrine sediments is almost negligible. The bathymetric limitations of marine faunas are less abruptly drawn than those of fresh-water molluscan faunas, but they tend in the same direction, viz., toward a decrease in the amount of bottom life in deep water. It is evident from these facts that the molluscan contribution to limestone sediments would be largest along the inshore margin of the littoral zone. The seaward decrease seems to be somewhat irregular. This contribution

[1] Charles Darwin, *Geol. Observations* (1851), p. 49.

[2] James Johnson, *Conditions of Life in the Sea.* A Short Account of Quantitative Marine Biological Research (1908), p. 176.

[3] Catherine Maynie, "Marine Biology at Port Erin," *32d Ann. Rept.* (1918), p. 12.

is very considerable and varies greatly along different parts of the shore line. In one area a mussel bed may have a population of 16,000 molluscs to every square foot.[1] Another area may be practically barren of animal life. These barren areas occur in the tropics as well as elsewhere. Dr. Fred C. Baker[2] has called the writer's attention to a portion of the northeast coast of Brazil where molluscan life is extremely scarce.

The data which has been recorded in connection with oyster culture is instructive in connection with any consideration of the part which marine molluscs play in furnishing material for limestones. It is reported[3] that the oyster when introduced into a Louisiana area where it had been previously unknown yielded 1,500 to 2,000 bushels per acre in two years. In this particular case the shells of a single mollusc contributed an annual average thickness of about 4 inches of calcareous material over the whole of the bottom on which they lived. These figures will serve to illustrate the very different rates at which marine shells contribute to the materials for limestone formation. Along those parts of a coast where large prolific species like the oyster are dominant the calcareous element of the sediments must increase much more rapidly than where less prolific and smaller species make up the fauna.

An important factor in the accumulation of marine shells in any given area is the delicate adjustment to a particular kind of bottom environment which characterizes most marine molluscs. The way in which this adjustment would operate with the sand-loving cockle of the English coast has been aptly pointed out by Hunt.

> Were the supply of sand in Torbay to be cut off, another common feature in geology might meet with an illustration, viz., the sharply defined zone in which fossils frequently occur. Were such supply to be cut off (and from the isolated patches of red sandstones that skirt the bay we see how much less it already is than it has been in past time) the sand-loving cockles could not fail to be affected, and might even become extinct in this locality at a very rapid rate.[4]

[1] James Johnson, *op. cit.* [2] Letter, June 12, 1912.

[3] Hugh M. Smith, *National Geographic Magazine*, XXIV (1913), 267.

[4] A. R. Hunt, "Notes on Torbay," *Rep. and Trans. Devonshire Association for the Advancement of Science, Literature, and Art*, X (1878), 186–87.

Bone beds.—A considerable portion of the fossil remains of vertebrate animals are found in "bone beds."

The term "bone bed" is in itself evidence of the tendency of vertebrate-fossil remains to accumulate in certain restricted zones and areas. Bone beds occur in each of the geological systems from the Devonian up. Even the few vertebrate remains which are known from the Ordovician may almost be said to represent a bone bed because of their abundance in a single zone. The Middle Devonian bone bed which forms the top of the Columbus limestone in Central Ohio is a representative Paleozoic deposit of this type. It has a thickness of 6 or 8 inches and consists of an "assemblage of millions on millions of generally imperfect but mostly recognizable organs or fragments of the bony structure of the forms of fish life most characteristic of the Devonian age."[1] This bed according to Stauffer[2] can be traced across the northern half of the state.

In the Upper Devonian shales of northern Pennsylvania occur numerous bone beds composed of the fragments of Catskill fishes. These beds of fish fragments are apt to vary from a few inches to a few feet in thickness and generally lie in the midst of beds which are barren.

The veteran collector C. H. Sternberg, who has probably collected more vertebrate fossils than any other living man, appears to have found the great majority of his fossils in bone beds. He states that

> all through the Belly River series of rocks are bone beds. In some places I secured hundreds, yes thousands of bones and teeth of many species, as well as shields of sturgeons and the enameled scales of gar-pikes as perfect as if picked up along a recent lake shore. There were also bones and shells of a great variety of soft shelled turtles and others, with beautifully sculptured shells; they range in size from less than six inches across to over two feet. Crocodile bones and the dermal or skin plates of plated dinosaurs were common. We secured hundreds of the pavement teeth of the ray Cope called *Myledaphus*, also countless vertebrae of the reptile *Champsosaurus*.[3]

[1] J. S. Newberry, *Monog. U.S. Geol. Surv.*, XVI (1889), 30.

[2] C. R. Stauffer, *Geol. Surv. of Ohio Bull. 10* (1909), p. 26.

[3] C. H. Sternberg, *Hunting Dinosaurs* (1917), p. 84.

C. M. Sternberg states that he knows of "no less than 7 bone beds in which only horned dinosaurs are represented."[1] Bone beds are frequently referred to in paleontological papers as "quarries." Concerning some of these quarries in Alberta Barnum Brown writes as follows:

> Frequently remains of many *Trachodonts* are found massed together in quarries, probably as a result of water action, in the Belly River and in the Edmonton strata, and there are two records of such occurrence in the Lance. In such quarries it is not exceptional to find *Trachodonts*, carnivorous dinosaurs, *Ceratopsia* and other remains commingled, although *Trachodonts* usually predominate.[2]

Various explanations have been offered for these aggregations of vertebrate remains, each of which is probably applicable to certain cases. Suffocation and burial by sand storms of the "frightened multitudes which had herded together in search of safety or courage" is a hypothesis offered by C. H. Sternberg.[3] Land vertebrates living in a wide alluvial plain might be periodically surrounded and herded together and drowned on the highest parts of an extensive area. In some instances prairie or forest fires may have been the compelling force which drove multitudes of land vertebrates into lakes and rivers. The fondness of most mammals for salt leads them, as is well known, to visit saline springs, and where these springs are in the midst of boggy ground may result in such aggregations of bones as those of the famous Bone Lick of Kentucky. Sir Charles Lyell[4] suggested still another way in which great numbers of large vertebrates may sometimes be drowned in lakes and rivers. He states that "It is well known that, during great droughts in the Pampas of South America, the horses, cattle, and deer throng to the rivers in such numbers that the foremost of the crowd are pushed into the stream by the pressure of others behind and are sometimes carried away by thousands and drowned."

[1] Letter to the writer, January 7, 1919.

[2] *Bull. Amer. Mus. Nat. Hist.*, XXXVII (1917), Art. X, pp. 282–84.

[3] Sternberg, *Life of a Fossil Hunter* (1909), p. 132.

[4] Sir Charles Lyell, *Travels in North America in the Years 1841 and 1842*, pp. 141–42.

Charles Darwin described a very curious habit of the guanaco or llama of South America which if shared by many of the extinct vertebrates may help to explain some of the bone beds of the Cretaceous and other rocks.

> The guanacos appear to have favorite spots for lying down to die. On the banks of the St. Cruz in certain circumscribed spaces, which were generally bushy and all near the river, the ground was actually white with bones. On one such spot I counted between ten and twenty heads. I particularly examined the bones; they did not appear as some scattered ones which I had seen gnawed or broken as if dragged together by beasts of prey. The animals in most cases must have crawled, before dying, beneath and amongst the bushes. Mr. Bynoe informs me that during a former voyage he observed the same circumstance on the banks of the Rio Gallegos. I do not at all understand the reason for this but I may observe that the wounded guanacos at the St. Cruz invariably walked towards the river. At St. Jago in the Cape de Verd Island, I remember having seen in a ravine a retired corner covered with bones of the goat; we at the time exclaimed that it was the burial ground of all the goats in the island.[1]

The periodic migration habit which characterizes many species of vertebrate animals tends strongly toward a highly irregular and localized distribution of their fossil remains. The migrating instinct which is remarkably developed in the majority of the birds of the temperate zone, in many species of fishes and in some of the mammals results in the great bulk of the species concerned dying in either its summer or winter habitat or in some especially hazardous portion of its semiannual journey. This habit is typically developed in the caribou of northwest Canada. The summer range and breeding ground of this deer lies several hundred miles to the north of its winter habitat. The number of individuals which move south each autumn from the Arctic barrens to the forested lake region of north central Canada numbers hundreds of thousands if not millions of individuals.[2] The bulk of the herds follow certain well-defined routes and generally cross certain east to west trending lakes at certain points. If we consider the thousands of years that this movement has been going on and the frequent casualties which have probably occurred in crossing on the new

[1] Charles Darwin, *The Voyage of the Beagle*, p. 172.

[2] E. M. Kindle, "A Note on the Migration of the Barren Ground Caribou," *Ottawa Naturalist*, XXXI (1917), 107–9.

autumn ice at points like Fond du Lac and Fort Rae on Great Slave Lake, we will see how at certain such points in the lakes and in the bogs which lay near the routes of migration the bodies of numberless caribou may have been entombed while other lakes and bogs remote from the north and south routes of migration might be entirely free from such remains.

Some species of animals which do not possess the seasonal migration instinct are subject to waves of migration which recur at irregular intervals often separated by two or more decades. Such waves appear to be caused by an excessive increase in the numbers of a species within its normal habitat. The rapid-breeding Siberian lemming is subject to these migration waves. Dr. Brehm[1] vividly describes the way in which impending famine starts an exodus from an overpopulated tundra.

> Famine threatens, perhaps actually sets in. The anxious animals crowd together and begin their march, hundreds join with hundreds, thousands with other thousands, the troops become swarms, the swarms armies. They travel in a definite direction at first following old tracks, but soon striking out new ones; in unending files—defying all computation—they hasten onwards; over the cliffs they plunge into the water. Thousands fall victims to want and hunger; the army behind streams on over their corpses; hundreds of thousands are drowned in the water or are shattered at the foot of the cliffs; the remainder speed on; other hundreds and thousands fall victims to the voracity of Arctic and red foxes, wolves and gluttons, rough-legged buzzards and ravens, owls and skuas which have followed them; the survivors pay no heed.[2]

The famine crazed hordes of migrating individuals which may result when a species greatly outbreeds the food possibilities of its habitat have probably furnished important contributions to the fossil bone beds of previous epochs as they are doing to those of the present.

Phenomenal increase in the animalcule life of fresh and salt water sometimes results in the pollution of the water and destruction of all the life in it. The oldest recorded example of this kind is probably the biblical one of the Egyptian plagues when the water of the Nile was as it were "turned to blood and all the fish died."[3]

[1] A. E. Brehm, *From the North Pole to the Equator*, p. 79.

[2] R. F. Scharff, *The History of the European Fauna* (1899), pp. 139–40.

[3] Exodus 7:20, 21.

The extraordinary abundance of flagellate animalcules is reported[1] to have caused red water for 200 miles along the coast of California and produced by their decomposition the death of shoals of fish and quantities of other marine animals. Phenomena of this kind must cause the sudden deposition on the sea bottom of unusual and extraordinary quantities of the remains of pelagic life of various kinds. If great numbers of fishes or other vertebrate animals were affected a bone bed might result.

Displacement of ocean currents.—Still another cause of discontinuity in the accumulation of marine fossils over extensive areas is to be found in the occasional shifting or displacement of ocean currents from parts of their usual routes by great storms. Professor Verrill encountered a striking example of this class of phenomena several years ago while dredging under the edge of the Gulf Stream, southeast of Long Island.

> One of the most peculiar facts connected with our dredging this season was the scarcity or total absence of many of the species especially of *Crustacea*, that were taken in the two previous seasons, in essentially the same localities and depths in vast numbers—several thousands at a time. . . . . An attempt to catch the "tile-fish" (*Lopholatilus*) by means of a long trawl-line on essentially the same ground where eighty were caught on one occasion last year, resulted in a total failure this year. It is probable, therefore, that the finding of vast numbers of dead tile-fishes floating at the surface in this region last winter, as was reported by many vessels, was connected with a wholesale destruction of the life at the bottom, along the shallower part of this belt (in 70 to 150 fathoms) where the southern forms of life and higher temperatures (48° to 50°) are found. This great destruction of the life was probably caused by a very severe storm that occurred in this region at that time, which by agitating the bottom-water forced outward the very cold water that even in summer occupies the great area of shallower sea in less than 60 fathoms along the coast, and thus caused a sudden lowering of the temperature along this narrow warm zone where the tile-fish and the crustacea referred to were formerly found.[2]

Barren areas.—Certain areas in many seas appear to remain permanently almost entirely barren of life though surrounded by areas crowded with marine life. One of the reasons for such barren

[1] *The Library of Natural History*, III (1906), 768.

[2] A. E. Verrill, "Evidence of Great Destruction of Life Last Winter," *Amer. Jour. Sci.*, XXIV (1882), 366.

areas in the case of sandy bottoms is doubtless the tendency of sands to move rapidly under current action and smother the marine life which attempts to live on them. Dr. G. A. Huntsman, who has been engaged in studying the conditions under which marine animals live in the Gulf of St. Lawrence, has directed attention to another factor in producing lifeless zones. He states:

> By means of these traps we discovered that a barren zone existed off the Cape Breton shore, comprising the part of the sloping bottom between the depths of 10 and 20 fathoms. In this zone the temperature at the bottom underwent violent fluctuations, often in the course of a day or so, at one time being as high as 65° F., and at another as low as 39° F. This was caused by the winds, for when the wind was blowing on-shore it drove the surface water against the coast and heaped it up forcing the deeper colder water down; then when it changed and blew off-shore the warm surface water was driven away from the coast and the cold water welled up from below to take its place, and so flooded the zone. The effect of this on the slow moving bottom animals may be imagined. Few of them would be able to stand such changes, but the active fishes are able to move up and down the slope and avoid these changes.[1]

Seasonal variation.—Another factor in the variation in the rate of sedimentation in the sea is the seasonal factor. The annual seasonal changes in the sea result in marked differences in the amount of organic materials deposited on the sea bottom during different parts of the year. The registration of seasonal changes by banding in the volume of clastic sediments in aqueoglacial deposits has been exhaustively discussed by Sayles.[2] Comparable with the great contrasts in the volume of lacustrine sediments deposited during different parts of the annual cycle are the different amounts of organic materials which the plankton life of the sea showers on the bottom in winter and in summer. It is possible that we may yet be able to interpret some of the fine lamination in sea-laid deposits in the precise terms of years. "In early spring there is a great awakening in the oceans comparable with the growing of the grass and the budding of the trees on land." This awakening corresponds to the time when the alkalinity of the sea is at a maximum.

[1] *Canadian Fisherman*, May, 1917.

[2] R. W. Sayles, *op. cit.*

Prof. Benj. Moore discovered that the sea around the Isle of Man was a great deal more alkaline in spring (say April) than it is in summer (say July); and then on examining monthly samples taken throughout the year he was able to show that the alkalinity which gets low in summer increases somewhat in autumn, then decreases rapidly during the winter, and after several months of a minimum begins to increase again in March, and rapidly rises to its maximum in April. That is the periodic change of alkalinity and it will be seen to correspond roughly with certain very important changes in the living microscopic contents of the sea and the connection between the two may be made out by inquiry into the nature and meaning of the changes in alkalinity. The alkalinity of the sea is due to the relative absence of carbon dioxide. . . . . We find that at Port Erin in March the water, not only on the shore, but also out in the open sea, is acid to phenolphthalein, while a month later it is distinctly alkaline to the same indicator and this change signifies an enormous conversion of carbon in the inorganic into carbon in the organic form, a turnover of such extent that it probably amounts to 20,000 or 30,000 tons of carbon per cubic mile of sea-water. . . . . Or we may imagine this same quantity of carbon as forming the bodies of all the organisms found in the sea all around the shores of the Isle of Man, in which case the 300,000 tons would be distributed through the zone of water extending to about one mile out from the shore and down to an average depth at that distance of, say, ten fathoms. Now all of these organisms have obtained their carbon from the carbon dioxide present in the sea-water in spring and it is absolutely certain that in the absence of this abundant supply of available carbon-food, the millions and millions or organisms in question could never have existed." . . . . "Practically all our food-fishes in the sea, except the herring, produce their eggs in winter or early spring. They are hatching out in vast quantities during the time that the alkalinity is rapidly increasing and the phytoplankton of diatoms is daily growing in amount."[1]

It is evident that the vast increase in the quantity of marine life during the spring and summer must be registered in sea-bottom deposition by a corresponding increase in the amount of diatom and other organic materials dropped on the sea bottom. We have therefore throughout the seas of the temperate and northern parts of the earth annually a summer period of maximum sedimentation following a winter period of minimum sedimentation.

CONCLUSIONS

The evidence appears to be distinctly against uniformity in sedimentation. Biologists in recent years have generally accepted

[1] W. A. Herdman, "Some Periodic Changes in Nature," *32d Ann. Rept. Liverpool Marine Biology Committee* (1918), pp. 23, 24, and 27.

the relatively new conception of succession as a process which results inevitably from the activities of each plant or animal community destroying by its own activities the possibility of indefinitely continued existence in the same place. The operation of this and other factors, some of which produce more sudden results, tend inevitably to vary the rate and shift the area of accumulation of the organic constituents of sediments. In a comparable manner sedimentation sets its own time limit on its operation in any given area. Alluviation terminates automatically when the deposits of a valley reach a thickness corresponding to the height of the maximum flood waters of the valley. Sedimentation ceases in a lake when the deposits approximate the lake surface. Although this familiar conception of the self termination of terrestrial sedimentation in fluvial and lacustrine waters has been generally recognized and applied to terrestrial sediments it has not been extended to marine conditions. But its application though less obvious is almost equally justified. In foreland structures the building of coarse deposits of sand, gravel, and shingle is limited vertically by the height to which wave action reaches. Horizontally the direction and strength of currents are the chief limiting factors. When these rather definite limits have been reached by a particular spit its supply of sediments goes elsewhere.

In areas remote from the shore line wave base and current action are determining factors in sedimentation. Wave base differs for different classes of materials as pointed out by Barrell.[1] It is deeper for fine than for coarse materials. Mud deposits can never build to the surface in the open sea because of the dissipating influence of the waves. Sand deposits fed by an abundant supply may, however, reach the surface. Whatever the upper limit of a particular formation may be, it will depend on the interplay of wave and current action, and when reached the further growth will be lateral or else diverted to a new area by a shifting of the flow of materials. Any adequate conception of marine sedimentation must include numerous great river-like currents some with intermittent activity, others periodic, while a few doubtless follow

[1] Jos. Barrell, "Rhythms and the Movement of Geologic Time," *Bull. Geol. Soc. Amer.*, XXVIII (1917), 778.

permanent routes in the sea bottom. Many of these probably move the finer sediments toward and over the border of the continental shelf as definitely as terrestrial streams move their sediments toward the sea.

Geologists and paleontologists may learn much regarding the rôle of marine currents from the keen analysis of living faunas which such investigators as Peterson are making. This author who has discriminated and mapped several sharply contrasted bottom faunas in the Skagerrak and Kattegat finds that

> The *Modiola* epifauna occurs especially where there is a strong current close to the bottom, clearing away the finer particles so that stones and shells lie exposed, affording sites for attachment for the *Modiola*, which may here occur in such numbers as entirely to cover the bottom (see Pl. IX) for great tracts in the current channels.[1]

The inferences which we can at present make concerning some of the conditions controlling marine sedimentation are based on such detached bits of evidence as have been brought together in this paper. It is hoped, however, that it will soon be possible to base conclusion relating to such problems on intensive studies of numerous selected areas of sea bottom in which areal mapping of bottom deposits will be an important feature.

[1] C. G. Joh. Peterson, "The Sea Bottom and Its Production of Fish Food," *Rept. Danish Biol. Sta. to Board of Agriculture* (1918), p. 15.

SOME STRATIGRAPHIC AND STRUCTURAL FEATURES OF THE PRE-CAMBRIAN OF NORTHERN QUEBEC

H. C. COOKE

PART IV

DIASTROPHISM

The evidence cited in the preceding pages indicates that previous to the end of the period of deposition of the Mattagami series no general orogenic movements took place in this region, but that such movements as occurred were of the gentle, epeirogenic type. After the deposition of the Mattagami series, intense orogenic movements went on, which folded the Mattagami and Nemenjish series and the Abitibi volcanics closely, and converted a large proportion of them into schists. By some writers this folding has been supposed to have accompanied the intrusion of the granite, and been caused by the hydrostatic pressure of the upwelling magma. Were this the case, the remnants of the older series should have dominantly synclinal or monoclinal structures, and there would be no general correspondence between the axes of the folds of the different remnants. Such a condition appears to obtain in the Grenville-granite complex in the Adirondacks, according to W. J. Miller.[1] However, it does not appear to be the case throughout Ontario and Quebec, where no dominantly synclinal or monoclinal structure exists, and where there appear to be a definite subparallelism of the axes of folding over considerable areas.

A tabulation of the areas which have been discussed, with their general structure and the strike of their axes of folding as nearly as determinable, is given on page 368.

The parallelism of the axes of folding of the different, rather widely separated areas is remarkable. All, it will be observed, fall within between N. 75° E. and S. 70° E. As the folds are

[1] W. J. Miller, *Jour. Geol.*, XXIV (1916), 587.

probably to be considered only as secondary folds on the flanks of the large regional major folds, parallelism is not to be expected between them, as the strike of the axes of such secondary folds is governed by the general strike of the strata at the point where they occur. The extension of data of the foregoing type over a large region will enable the nature of the great regional folds to be worked out; but this cannot be done now, as the area under discussion, though large, is small compared with the size of the Labrador peninsula.

Area	Structure	Strike of Axis
Kenoniska	Anticline	S. 75° E.
Lucky Strike	Anticline	S. 75° E.
Brock	Anticline	N. 85° E.
Opawika	An-Sy-An	N. 75° E.
Father's Lake	Syncline	S. 75° E.
Windy Lake	Monocline	E.–W.
Nemenjish		N. 60° E.
Eau Jaune		S. 70° E.
Mattagami	Probable anticline	N. 80° E.
Pontiac	Probable anticline	E.–W. E.

The general parallelism of axes indicates that the regional folding was not caused by the hydrostatic pressures of batholithic intrusions, but by a compressive stress affecting large areas uniformly; while the lack of shear in the granites shows that the folding occurred before their intrusion. This conclusion does not of course invalidate the possibility that the intrusions followed the folding very closely.

The folding may therefore be dated as post-Mattagami and pre-batholithic. It resulted in the formation of close folds with an east-west axial trend and cross folds of a much more open type. The cross folding has given a plunge of some 20° to the axes of the major folds.

In addition to the post-Mattagami folding movement, some evidence exists that there was an earlier folding, affecting not the region under discussion, but that to the south, the borders of the continental segment, in Grenville time. This accompanied or closely followed the intrusion of the earlier granite, but preceded the intrusion of the anorthosite. In the Adirondacks, Cushing,[1]

[1] *Reports of the New York State Museum.*

Kemp, and Smyth describe the Grenville series and older granite-gneiss as much more metamorphosed than the intrusive anorthosite, a fact which may indicate an early folding, but may also be due to the greater competence of the anorthosite to resist the later folding. The evidence is slight, but it is very possibly the case that the marginal intrusion of granite accompanying the uplift of the Grenville continental segment at the close of Grenville time was accompanied by marginal folding movements. If this is true, we should expect to find in these districts the equivalents of the Mattagami series resting with structural as well as erosional unconformity on the Grenville. This seems to have been the condition in the Madoc district, where according to Miller the Hastings series, a possible equivalent of the Mattagami series, rests against the upturned edges of the Grenville.[1]

GRENVILLE (?) SEDIMENTS ON THE WEST SIDE OF HUDSON BAY

While no sediments that can be definitely asserted to be of Grenville age have as yet been described to the west of Hudson Bay, it is interesting to note that there are a number of areas of rocks whose petrography is similar to that of the Grenville series, and which, like them, are intruded by granite apparently of very great age. The reports of Tyrrell and others in this region have yielded a number of more or less doubtful occurrences of these rocks. A few others have been described to the writer by present members of the staff of the Geological Survey. In the vicinity of Lake La Ronge, W. McInnes has reported[2] crystalline limestones and basic intrusives, greatly folded and altered, and intruded by the granite gneisses of the district. E. L. Bruce has informed the writer that he found ancient garnet and staurolite gneisses intruded by granites around Wekusko Lake, Manitoba. One of the gneisses analyzed is undoubtedly of sedimentary origin. Tyrrell, studying this same area, reports that this gneiss "grades downward into the greenstone schists"; apparently indicating a conformable relation between the two, similar to that described in this paper. F. J. Alcock states that to the northeast of Lake Athabaska he found an

[1] *Rept. Ont. Bur. of Mines*, Part 2, 1914, p. 12.

[2] *Geol. Surv. Can. Mem.* 30, 1913, p. 48.

area of garnetiferous mica gneisses, intruded by granites. The occurrence of such sediments is of great interest, as indicating the possibility of future correlation with the eastern side of Hudson Bay.

THEORETICAL CONSIDERATIONS

Conditions of Extrusions of Abitibi Volcanics

The nature of the floor upon which the Abitibi volcanics were poured out cannot be more than a matter for conjecture. No trace has as yet been found of the rocks which once composed it, to show whether they were sedimentary or igneous, flat-lying or folded. Other facts are, however, more certain.

In the following section the conclusion is drawn from a consideration of the nature of the Grenville sediments that the Grenville series in the interior of Quebec was deposited under continental or shoal-water marine conditions. The region was therefore a continental plateau, or positive element, even at this time. As evidence is lacking of the occurrence of any great earth movement between the extrusion of the Abitibi volcanics and the deposition of the Grenville series, it would be reasonable to conclude that during the extrusive period also the region must have been a positive element. Some direct evidence on this question is obtainable from the lavas themselves, using pillow lavas and bedded tuffs as criteria of subaqueous extrusion.

On Obatogamau Lake all the lavas, even the basal basalts, show pillow structures. On Kaopatina Lake and eastward to Father's Lake, the basalts are not pillowed, but the overlying lavas have the structure well developed, and interbanded tuffs are well bedded. On Tush Lake and the areas to the northward, none of the lavas are well bedded. While this line of evidence has not been worked out in detail throughout the entire area, the facts obtained suggest that the extrusive period was one of gradual submergence. The earliest recognized shore must have lain between Obatogamau and Kaopatina lakes, and a westward transgression of the sea took place thereafter. The submergence evidently went on after the extrusion of the lavas was complete, since garnetiferous gneisses

identical with the rocks of the Grenville series are found up to the shores of James Bay.

Alternative to the hypothesis of marine transgression lies the possibility that at this time the land was covered by a series of large lakes. If the land remained above the level of the sea, the outpourings of lava that took place must have filled the stream valleys and utterly disorganized the drainage; lakes must have been formed as a result, and if the region was one of low relief, as it will presently be shown appears probable, these lakes may have attained sizes comparable to those of the great glacial lakes of Pleistocene times. Such a condition would explain the facts stated, as well as marine transgression.

Topographically, the surface on which the lavas were poured out seems to have been one of low relief. Had high mountains existed at the time, the remains of the peaks, around which the lavas would have flowed, should surely be found now penetrating into at least the lower beds above, which are now on edge. Nothing of the sort has come to light. Again, had the extrusions been thrown out from high peaks, such as the volcanic cones of the present day, we might now expect to find sudden changes of strike near the volcanic centers, due to the occurrence of steep depositional dips. This has not been observed. The conclusion may therefore tentatively be drawn that the flows were extruded as fissure eruptions, at least in the case of the more widely distributed basic lavas, and to have flowed out over a surface of fairly low relief. More detailed field work is necessary, with careful mapping of the areal boundaries of separate flows, to establish this conclusion.

Conditions of Deposition of the Grenville Series

Areal distribution.—A careful search has been made of the reports of the explorers of northern Quebec and Labrador, and determinations made from their descriptions of the location of areas of the Grenville series, using as criteria for its determination mainly petrographic similarity and geological relations. Many descriptions were met with of rocks which bear a strong resemblance to certain phases of the Grenville, but are likewise indistinguishable from the Pontiac or some other highly altered sedimentary series.

These are not included on the accompanying map; the bodies mapped are confined to those highly garnetiferous types, with or without limestone, which are peculiarly characteristic of the

FIG. 13.—Map to illustrate the distribution of the limestone member of the Grenville series. Limestone is absent on the Hudson Bay side of the heavy black line and present on the southeast side.

Grenville. The areas shown on the map (Fig. 13) are those in which the amount of the Grenville series present is so large and its

characteristics so definite that its identification can scarcely be doubted. The dotted patches are those in which the amount of Grenville present, relative to that of the granite which has intruded it, is small, so that its identification is more open to argument. Even in these cases, however, the effort has been made, as stated, to weed out the doubtful cases and include none but those in which identification is fairly certain. The results show the presence of the Grenville over the whole interior of the Labrador peninsula, wherever exploration has been carried, as well as in Baffin Land and the long-known districts to the south.

The study of the older reports, together with the writer's own field work, has brought to light a peculiarity in the distribution of the limestone member of the series. Limestone is found in Baffin Land, in places along the Labrador coast, and throughout southern Quebec and Ontario, as well as in the Adirondack region; but little or no limestone has been described throughout the interior plateau of northern Quebec. It has been considered by certain authors that the lack of limestone in this region is due to its solution by the intrusive granite, where the granite is present in sufficiently large amount. This opinion does not appear to be well founded. In the section northward along the Gatineau River, above the town of Maniwaki, the writer found that the limestone member decreases in relative amount, with corresponding increase of the clastic members of the series, until it disappears altogether, without any notable increase in the amount of intrusive granite which is present throughout in considerable amount. In the Nemenjish area, there are at least several hundred feet of clastics, entirely free from intrusive granite. With them there are interbedded only two bands of limestone, each about a foot in thickness. These facts seem explicable only on the hypothesis that the limestone never was deposited in the localities mentioned; in other words, the lack of limestone in certain areas is due mainly to a primary difference of sedimentation rather than to removal after deposition by the granite. A preliminary attempt has been made, from a study of the reports, to determine the position throughout the Labrador-Quebec region at which this change in sedimentation took place, and to indicate it on the map (Fig. 13) by a heavy black line. On the Hudson Bay side of this line little or

no limestone has been found, but on the other side of the line limestone in considerable amount.

The existence of such a definite boundary is of great significance in considering the conditions of deposition of the Grenville series. We have an interior region in which, for some reason, conditions were unfavorable for the deposition of limestone; while, beyond the margins of this region, limestone was deposited freely. Two possibilities present themselves to explain this fact. The portion of the Grenville within the limestone boundary may be of terrestrial origin, in which case the limestone boundary will represent approximately the location of the Grenville shore line; or the whole series may be marine, but the clastic sediment within the limestone boundary may have been so abundant that limestone was not formed there. In either case the limestone boundary represents a topographic break, where an interior plateau fell off sharply to a lower level. The solution of this problem therefore depends on the determination of the marine or non-marine origin of the Grenville sediments within the limestone boundary.

The data at hand are not sufficient for the solution of this problem, since the comparatively small Nemenjish area is as yet the only one which has been studied. The known facts, pro and con, may be summarized as follows:

A. In favor of a non-marine origin of the series where limestone is absent:

1. The Nemenjish sediments as a rule have the composition of an altered greywacke as if derived from older rocks by disintegration without much decomposition. They show small variations in mineral composition, but these variations appear to be due to variation in the composition of the older rocks from which they were derived, rather than the variations due to normal weathering and consequent separation into sandstone and shale constituents. True quartzites, shales or slates, and limestones are conspicuous by their absence, or their presence in very small amount, in the northern region, although they are present in greater amount in the marine division of the series beyond the limestone boundary—a natural result of transportation over greater distances.

2. Although remnants of the Grenville sediments appear to be scattered over the whole of the Labrador plateau, it is not yet proved

that they once formed a continuous sheet over this area. It is equally possible that they may have been deposited in discontinuous basins.

3. If the origin of the sediments was marine, a study of the map shows that it will be necessary to postulate that the land area from which they were derived occupied part of the present area of Hudson Bay. It is difficult to conceive of the transport of sandy sediments from a land area in this position to the eastern Ontario district or the Labrador coast.

B. In favor of a marine origin:

1. The entire lack of conglomerates or coarse-grained clastic sediment in the known portions of this series is strongly against the hypothesis of a non-marine origin. Deformation has not been so great as to destroy such textures, as their preservation in the Mattagami series shows.

2. In the Nemenjish area all the rocks are well bedded, usually in beds twenty or more feet in thickness. No trace remains of cross-bedding, lens-shaped beds, or other structures characteristic of terrestrial deposits. This area might of course have been part of the site of a large lake.

3. The greywacke-like composition of the rocks might equally well be explained on the basis of the lack of vegetation in these early times, so that the composition might not argue either for or against the marine origin. Where vegetation was lacking and precipitation abundant, sediment would be removed as fast as disintegration took place, so that complete decomposition of the rock constituents by weathering might not have taken place.

Conditions of Deposition of the Mattagami Series

Areal distribution.—The Mattagami series is not known certainly outside of the region under discussion, as its existence and age relations have been recognized only within the last few years. Apparently, however, it was once fairly uniformly distributed over northwestern Quebec, at least as far north as the East Main River, where sediments of similar composition and degree of deformation are described by Low.[1] The writer has not been able to identify the

[1] *Geol. Surv. Can., Ann. Rept.*, VIII (1896), Part L.

series elsewhere in northern Quebec from the reports. The Timiskaming, Sudbury, and Hastings series to the south and southwest may possibly be of the same age, though a definite correlation cannot now be made.

The same difficulties obtain in the Mattagami series as in the Grenville series with regard to a marine or non-marine origin. Generally speaking, the composition of the two series is very similar, that of an altered, rather impure sand, implying conditions of rapid weathering and deposition without extended decomposition of the rock constituents. All the arguments for and against a marine origin that have been previously cited in the case of the Grenville hold also in the case of the Mattagami series, with the exception that the Mattagami series includes a heavy basal conglomerate of such thickness that a non-marine origin for this member at least seems very probable. In the Lucky Strike area, where the series has been greatly thinned by shearing, the present thickness of the conglomerate band is approximately 300 feet. In the Kenoniska area there are two bands of conglomerate, separated by a thick, massive, basic greywacke, with very little trace of bedding and holding an occasional pebble. The thickness of the whole is very difficult to estimate on account of the probable thickening of the formation at the nose of the fold by flowage, and uncertainty as to the plunge of the fold. A minimum estimate by the writer, however, yielded a thickness here of at least 1,000 feet. According to Barrell, marine conglomerates are rarely over 100 feet in thickness. If this is true, the conglomerate member of the Mattagami series is probably of non-marine origin.

Diastrophism

Certain considerations seem to indicate that the great diastrophic movements which followed the deposition of the Mattagami series were connected with, or resulted in, the primary formation of the great geosyncline of Hudson Bay. These may be summarized as follows:

1. If the Nemenjish and Mattagami series are considered to be marine formations, their distribution indicates that the only possible land mass which would supply the necessary sediments must have occupied the present position of Hudson Bay.

2. Leith[1] has shown that the formation of the great Lake Superior syncline began in pre-Keweenawan time, and suggests indirectly that it may have begun to form very much earlier, even in the pre-Huronian. The formation of a structure of this size must have been accompanied by profound deformative effects on the rocks for a long distance to the north and south. The evidence from the parts of northern Ontario and Quebec dealt with in this paper indicates that they have been affected by only one intense folding movement of pre-Keweenawan age, the post-Mattagami movement. The Bruce series, or Lower Huronian of the north shore of Lake Huron, and the Cobalt series which overlies it, where not affected by Keweenawan deformation are only gently folded and rest on a folded and peneplaned surface. It seems reasonable therefore to correlate the post-Mattagami folding with the primary formation of the great synclines of Lake Superior and Hudson Bay. The region between, under this hypothesis, is an anticlinorium, and was probably mountainous, so far as can be judged from estimates of the thicknesses of rock removed during the pre-Huronian peneplanation.

3. The Nastapoka sediments on the east shore of Hudson Bay are classified by Leith[2] as of Keweenawan age, with perhaps some Animikee rocks included. The presence of these rocks shows that at this time Hudson Bay was already a synclinal depression in which sediments were being deposited. Their deformation shows, in addition, that the folding movements by which it was formed were still going on. This history is parallel to that of the Lake Superior basin, the deformation of which continued throughout pre-Cambrian time up to the end of the Keweenawan.

REGIONAL HISTORY

In the earliest times of which we have record the northern Quebec region appears to have been a continental plateau of low relief. This plateau included not only northern Quebec, Labrador, and probably Hudson Bay, but also Baffin Land, eastern Ontario, parts of New York and Vermont, and perhaps a large area to the

[1] *U.S. Geol. Surv. Monograph 52* (1911), p. 622.

[2] *Economic Geology*, V (1910), 227–46.

west and southwest of Hudson Bay. What its further extent may have been is not known. The nature of the rocks that composed the plateau and formed the floor on which later rocks were laid down is yet unknown. The first event of which record remains is the extrusion of vast amounts of lavas, which spread in sheets over the greater part of it. Many of these lavas possess pillow structures and are interbanded with beds of tuffaceous sediments. Both of these lines of evidence indicate subaqueous extrusion; so that either the sea covered portions of the plateau at this time or the earlier extrusions of lava so disorganized the drainage as to create large lakes, in which ellipsoidal lavas and bedded tuffs were laid down. In the northern Quebec district the oldest lavas found are of basaltic composition. They were succeeded by more acid types as extrusion went on, so that the basalts are overlain successively by porphyritic basalts and andesites. Between the andesite flows, beds of chert are occasionally found, which probably represent portions of the load of magmatic waters accompanying the flows. Near or at the top of the andesite flows, beds of coarse tuff are found locally, indicating that the period of andesite extrusion ended with volcanic explosions. The period of volcanism closed with a number of local and small extrusions of quartz porphyry. In places this porphyry forms a breccia instead of a massive flow. The brecciated texture has been shown to be due porbably to subaqueous extrusion, and thus corresponds to the pillow structure in the more basic lavas.

At the close of the extrusive period deposition of sediments began. The lowest beds are of a rather basic, tuffaceous composition. These beds soon give place to others which have more the composition of impure sands and are now altered to micaceous schists containing a few garnets. Higher in the series a further change in composition takes place, probably by an increase in the lime content of the beds, which is marked by the appearance of garnets in great numbers. Interbedded with the garnetiferous mica gneisses are beds of garnetiferous hornblende gneiss and an occasional thin bed of crystalline limestone. These sediments, locally termed the Nemenjish series, are correlated with the Grenville series. It is as yet uncertain whether they are to be con-

sidered as of marine or of terrestrial origin. They are separated by a fairly sharp boundary from the known marine portion of the Grenville to the south, in which much limestone is found. This boundary represents approximately the position of the ancient shore line, if the sediments to the north are of terrestrial origin; if the sediments to the north are marine, it represents a topographic break, separating an area of very shoal water deposition to the north from an area of deeper water deposition to the south. In the latter case, the sediments of the Grenville must have been derived from a land area occupying the site of Hudson Bay.

At the end of the Grenville period of deposition, uplift appears to have taken place, and a period of erosion ensued. This was sufficiently long to remove all or the greater part of the Grenville series from much of the interior plateau, where presumably it was thinnest, since in the area between Lake Mistassini and James Bay the supposed Grenville has been found in only two places between the lavas and the Mattagami sediments.

The emergence just described appears to have been accompanied or closely followed by intrusions of granite in the southern portions of the plateau. This "older granite" has not yet been recognized farther north than Lake St. John. There is some evidence to show that folding movements also accompanied these granite intrusions, causing deformation of the rocks of the southern edge of the plateau. After the intrusion of the granite and the folding movements, if any, were ended, masses of anorthosite and feldspathic gabbro were intruded. These have been found as far north as Lake Chibougamau, but are more numerous and larger in the southern districts, where the earlier granite occurs. The localization of two such widespread intrusions within similar limits is probably due to some common cause; perhaps to the presence of lines of weakness in the older rocks caused by the folding just mentioned. No important orogenic movement appears to have accompanied the anorthosite intrusion.

The next event in the history of the region was the deposition of the Mattagami series, which may or may not have been accompanied by marine submergence. The thickness of the basal conglomerate of the series indicates that at least this member probably

accumulated under non-marine conditions, if Barrell's conclusion as to the thickness of marine conglomerates is to be accepted. The deposition of the conglomerate was followed by that of thick beds of arkose and greywacke, locally with a little quartzite. A limestone member may have been present in beds laid down beyond the southern margin of the interior plateau.

Following the deposition of the Mattagami series came a period of intense orogenic movement and mountain-building, during which all the rocks were folded closely along east-west axes and gently along north-south axes. The more incompetent rocks were converted into schists. Following the folding was the great intrusion of later granite, which stoped away and digested vast quantities of the older rocks, and which, now exposed by erosion, underlies the major part of the region.

A period of erosion followed, so long that the mountains of the last folding were cut down nearly to base-level, and the granite batholiths laid bare. No recognizable trace has yet been found of the sediments which resulted from this erosion and which must have been deposited somewhere during this period. The next event of which any record remains is the deposition of the Bruce series on the peneplained surface of the older rocks on the north shore of Lake Huron. This indicates a third period of submergence, which appears, however, to have been of small areal extent. Emergence and the erosion of about 1,600 feet of the Bruce series followed, with further gentle folding, after which a more extensive submergence initiated the deposition of the Cobalt series. At this time the sea transgressed certainly as far northward as Lake Abitibi, and possibly to Lake Mistassini and beyond. The nature of the Cobalt sediments indicates that the sea was probably very shallow. Glacial conditions obtained at this time, according to Coleman, M. E. Wilson, and others, and influenced the character of the sediments laid down. The final event in the history of the region, so far as traced here, was the intrusion of gabbro and diabase into the older rocks in sills and dykes, preceding or accompanying further gentle folding movements.

Climate and life.—Our knowledge of the climate and life conditions that prevailed in these early times is exceedingly scanty,

and all of it so inferential that it is of small value. The presence of the great thicknesses of limestone in the Grenville series is, however, strongly suggestive of the existence of lime-precipitating organisms even at that early period, although it is of course conceivable that the precipitation of lime at that time may have been chemical. The common presence of scales of graphite in the quartzite and crystalline limestone and the also common presence of H_2S apparently included in the limestone crystals are, however, both rather strongly corroborative of an organic origin. Whether life extended to the land at this time is more doubtful. If it did, it must have been of a very sparse nature, with little restraining effect on the movement of soils under erosive influences. The nature of the clastic sediments that were deposited throughout Grenville and Mattagami time indicates conditions under which the soil was removed from the land surfaces without the prolonged weathering and thorough decomposition of the mineral constituents that a good covering of vegetation promotes.

The climate of the Grenville period may be inferred to have been mild for the following reasons: (1) If the limestone of the series is of organic origin, it would imply the existence of a warm epicontinental sea. (2) The Grenville sediments, though not well weathered, are as a rule much more acid than the basic lavas from which in all probability they were largely derived. This would indicate, in the absence of vegetation, a warm climate favoring the rapid decomposition of the rock constituents. (3) The enormous extrusions of lava which took place preceding the deposition of the Grenville must have been accompanied by the exhalation of huge volumes of carbon dioxide into the atmosphere. The presence of this carbon dioxide may have had some effect in ameliorating the climate of the period.

The climate during the Mattagami period is more in doubt, but it was probably cooler than that of the Grenville period. The presence of limestone in very small quantities only might suggest a sea colder than that of Grenville time, in which lime-secreting organisms did not exist in such profusion. The clastics, though frequently similar to the Grenville, are in general more basic and less weathered. This might also indicate colder climatic conditions.

SUMMARY

This paper first describes methods which the writer has used for the determination of structure in the volcanic flows, often termed "Keewatin," that form the oldest known rocks of northern Quebec. These methods, applied to four areas of these volcanics on the Opawika River, a tributary of the Nottaway, have resulted in the determination of a similar sequence of extrusion in each area. The sequence is one of increasing acidity, and consists of basalt at the base, overlain successively by feldspathic basalt characterized by large phenocrysts of feldspar, andesite, dacite, and rhyolite. All members of this series are not necessarily present in any one locality, but their succession when present is invariable as stated.

The paper also establishes the occurrence in northern Quebec of two important sedimentary series, both apparently of pre-Huronian age. One of these, the Nemenjish series, has been found by the writer in one locality only. It consists of a series of garnetiferous gneisses, mainly the recrystallized form of impure sandstones, which still exhibit bedding and other characteristics of sediments. The rocks rest with structural conformity on the surface of the ancient lavas, and some evidence is given to show that they probably are to be correlated with the Grenville series. The other sedimentary series, the Mattagami, has been found in five different areas. Evidence based on the character of the sediments in each area, the sequence of the formations in each series, the structures, and the relations to older and younger rocks, is cited to show that they are all of one age. The evidence relating to their position in the geologic column is less satisfactory, but they appear to overlie the Nemenjish series with unconformity, and to be much older than the Lower Huronian, or Bruce series.

In addition to these matters of principal interest, the paper discusses a number of theoretical considerations. One of these may particularly be mentioned. The explorations of northern Quebec show the existence of a fairly sharp boundary line, on one side of which limestone is a member of the Grenville series, while on the other side it does not appear. The significance of this line is discussed, and the conclusion reached that it represents an ancient topographic break, either a shore line or the boundary of a submerged plateau.

THE THURMAN-WILSON FAULT THROUGH SOUTHWESTERN IOWA, AND ITS BEARINGS[1]

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WHY THE EXTENSION OF THE FAULT HAS BEEN OVERLOOKED

It may seem remarkable that an important fault should extend from near the southwest corner of Iowa to the central part of the state, with indications that it may actually extend to the "Driftless Area," and very little evidence of the presence of such a fracture exist in the literature of the state.[2] There are, however, reasons for this lack of previous recognition. The strata of the Missouri stage of the Pennsylvanian, in and beneath which nearly all of the displacement in southwestern Iowa took place, is concealed over

[1] Published with the approval of the director of the Iowa Geological Survey.

[2] The following important references may be noted:

J. E. Todd, "On the Folding of the Carboniferous Strata in Southwestern Iowa," *Proceedings of the Iowa Academy of Science*, I, Part I (1889), 61; "Some Varied Conclusions in Iowa Geology," *ibid.*, XIII (1906), 184.

G. L. Smith, "Carboniferous Section of Southwestern Iowa," *Iowa Geol. Surv.*, XIX (1909), 612.

C. R. Keyes, "Controlling Fault Systems of Iowa," *Proc. of the Iowa Acad. of Sci.*, XXIII (1916), 103; "Extent and Age of the Cap-au-Gres Fault," *ibid.*, XXIV (1917), 61.

Keyes's 1916 article was published during the summer, a year later than the field work by which the present writer discovered that near Stennett the Thurman-Wilson fault of Todd and Smith did not become an anticline but continued as a fault. In Keyes's two papers he is chiefly concerned with the Fort Dodge and the Cap-au-Gres faults, but in spacing the faults in his first paper he represents the "Red Oak fault" (the term he uses for Todd and Smith's fault between Thurman and Wilson quarries) as extending far to the northeast without giving any reason for opposing Smith's view that the fault became an anticline near Stennett, and calls the throw four hundred feet instead of three hundred feet, as reported by Smith. He also continues this fault line west to Hebron, Nebraska, without stating his reason for disagreeing with the geologists of Nebraska. However, it should be noted that near Bloomington in Franklin County, about seventy-three miles west of Hebron, Professor Erwin H. Barbour mentions and illustrates "one major and several minor faults of one to four feet displacement" (*Nebraska Geol. Surv.*, IV, Part VII, Pl. 12).

much of the area by a thick deposit of Dakota sandstone; and the entire area is deeply covered with drift, through which almost no outcrops of underlying strata appear. Especially is this true of the Missouri stage in the northern half of the area, the area north of the fault plane. Further, the Missouri stage in southwestern Iowa is represented by fourteen different sets of limestone beds separated by intervening beds of shale. The limestones themselves have shaly partings of various thicknesses, and the shaly members have limestone beds. Through all these beds there are the same species of fossils and the same general assemblage of forms, so that at present, at least, the worker who uses the fossils must associate the assemblage and relative abundance of fossils with the sequence of the beds. In this way a few lines of evidence can be made out that have an important bearing. Detailed work later on the fossil content and the relation of each bed will doubtless yield valuable returns.

South of the fault plane the varying dip of the strata accords in places with the slope of the stream beds; and no information had appeared in that area that revealed what beds became thinner beneath the drift.

THE FAULT

The writer finds that the Thurman-Wilson fault of 300 feet near the Missouri river in Fremont County does not become an anticline[1] toward Stennett, but that it is a normal dip or slightly oblique fault, extending between Fox quarries in the extreme southern part of Cass County and Briscoe (three miles further east), with upthrow on the north side, with displacement of 284.5 feet, and with fault plane dipping steeply to the southeast. This line of fracture continues northeast across Adair County, either in a slightly curved line or in a parallel fault or faults (Fig. 1). The southeast part of Guthrie County is the limit toward the northeast to which the writer has thus far traced the evidence of faulting in the field.

At the few places where a measurement of dip was obtainable a marked irregularity of dip was found that in general was at right angles to the strike of the fault plane, and thus at right angles to

[1] G. L. Smith, "Carboniferous Section of Southwestern Iowa," *Iowa Geol. Surv.*, XIX (1909), 636.

the general dip of the strata in that quarter of the state. North of the fault the upthrow side has been removed by erosion till no esacrpment has been left, while on the downthrow side the lesser amount of erosion has left strata far to the east, with offset of thirty-five and a half miles. North of the fault plane the strata beneath Lewis, Cass County, are seventy feet thinner than recorded in the log of the deep well at Clarinda, Iowa; and south of the fault

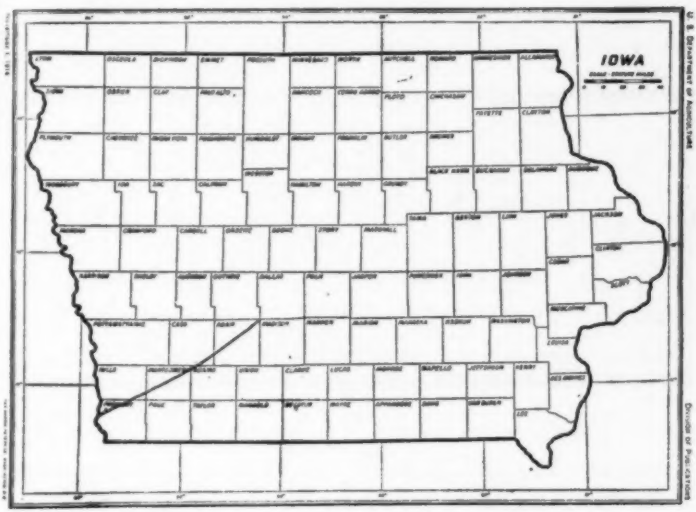

FIG. 1

plane they diminish in thickness 235 feet further within a distance of 41 miles from Brişcoe, Adams County, to the "Backbone" west of Winterset, in Madison County. The most marked thinning is immediately beneath the Oread limestone, where in Missouri Hinds and Greene report a faunal break.[1] This is to be noted in contrasting a section northeast-southwest north of the fault plane with a parallel section south of the fault plane. The section from Reno to Briscoe across the fault plane connects these two sections (Fig. 2).

[1] Hinds and Greene, "Stratigraphy of the Pennsylvanian Series," *Missouri Bureau of Geology and Mines*, XIII (2d series, 1915), 155.

In order to express the relation of the beds that outcrop along Middle River in the eastern part of Adair County it has seemed desirable to represent the base of the Deer Creek substage as it meets the bed of Middle River, which in a straight line is ten and three-fourths miles northwest of the base of the Oread substage where it outcrops in Harrison township. As the strata rise to the north this makes it appear as if the Tecumsey shale became thicker to the northeast, when in reality all of the strata become thinner in that direction. In both these diagrams the dip is magnified eighty-eight and a third times.

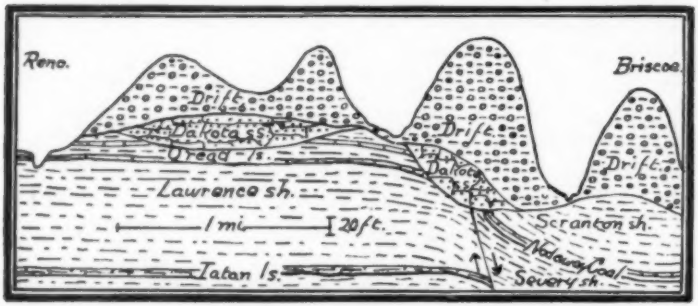

FIG. 2

The effect of this faulting on the location of outcrops is expressed in the block diagrams representing the changes that have taken place. It should be particularly noted that the limestone (Oread) which, on the north side of the fault plane, appears at Lewis and at the Fox quarries in the southwest part of Cass County, appears, on the south side of the fault plane, close to Middle River as it leaves Adair County, and also extends into the southwestern part of Madison County (Figs. 3 and 4).

IMPORTANT BEARINGS

Coal.—For the first time we now recognize why Nodaway coal found in the southern part of southwestern Iowa is not also found in the northern part of southwestern Iowa, except in a small area close to Thurman, Fremont County. Prior to this it was supposed

that the fault at Thurman changed into an anticline near Stennett, in which case there ought to be Nodaway coal north of the anticline. The recognition of the fault should prove of considerable economic value in preventing expenditure for prospecting for the Nodaway coal seam north of the fault.

The presence of the fault with uplift of 284 feet north of this fault plane is a new factor of importance bearing on the question

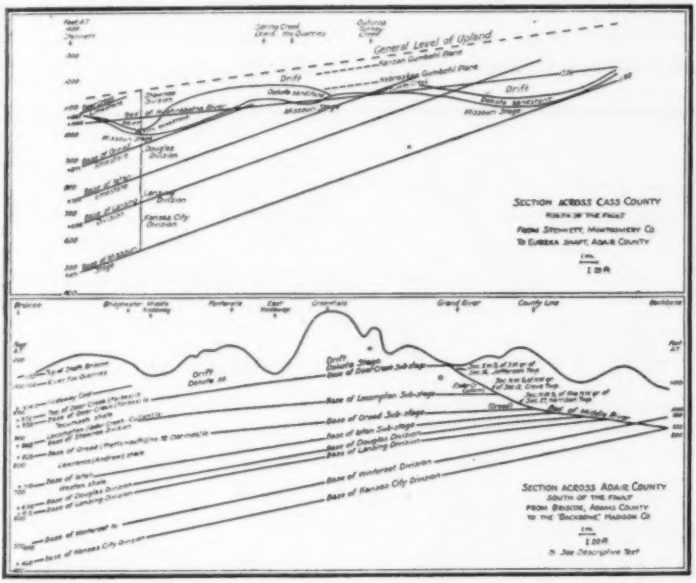

FIG. 3

of the depth of the Des Moines stage (the chief coal-bearing beds) farther north in the west central part of the state, even though the determination of the position of such beds is complicated by warping of the strata (if not by other faulting), by the great unconformity beneath them, and by the pre-Cretaceous erosion of their surface. The presence of thick beds of Dakota sandstone above the Des Moines stage and of thick deposits of drift above the

Dakota sandstone, apparently preclude the possibility of successful mines even if coal were located.

The presence of this fault and of others in a parallel direction with uplift to the north has also an important bearing with reference to the distribution of coal toward the north and northeast that is very noticeable in northern Adair and southern Guthrie and Dallas counties,[1] and, combined with erosion, explains the westward trend of exposures of the Des Moines stage in this region. It also introduces a new factor to combine with unconformity at the base of the Des Moines stage to explain why coal is found in certain localities (as near Panora and Boone) and not in others.

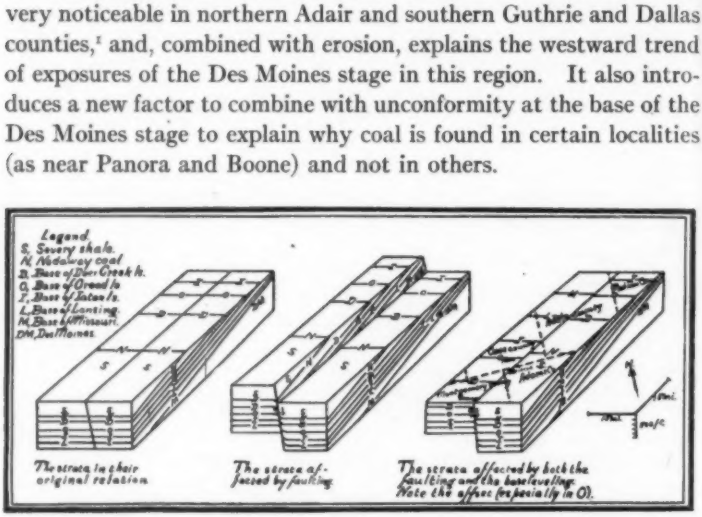
Legend
S. Savery shale
N. Nodaway coal
B. Base of Dwr Creek lr.
G. Base of Oread lr.
I. Base of Eaton lr.
L. Base of Lansing
M. Base of Missouri
DM. Des Moines
The strata in their original relation
The strata affected by faulting
The strata affected by both the faulting and the base leveling. Note the effect especially in O.

FIG. 4

Oil.—The presence of a dip fault extending through southwestern Iowa toward the oil fields farther southwest, with strata in Iowa monoclinal, dipping southwest, and crossed by low anticlines,[2] present a series of facts that cannot be overlooked with reference to oil, even though no traces of oil have been found. Across the river in Nebraska a little fault exists in Jones Point

[1] In view of the presence of this parallel fault Bain's report on Guthrie County makes very interesting reading (*Iowa Geol. Surv.*, Vol. VII). On pp. 428–29 he describes the upper division of the Des Moines stage as duplicating the lower division, and on p. 455 states that beds found "probably represent the upper portion of the Cherokee shales." Leonard (VIII, 91) speaks of an anticline in the southwestern part of Dallas County, the county next east of Guthrie County.

[2] George L. Smith, "Carboniferous Section of Southwestern Iowa," *Iowa Geol. Surv.*, XIX, 624.

that Todd[1] and Smith[2] thought a continuation of the Thurman-Wilson fault in Iowa. It seems strange that there should be a displacement of 300 feet on the Iowa side of the river and of but a few feet on the Nebraska side, and even more strange now that we know that the fault continues to the northeast with but little diminution of displacement to at least near the center of Iowa. Perhaps there is a displacement further north or south in Nebraska that has not yet been located.

Why no oil has been found in southwestern Iowa, southeastern Nebraska, and northeastern Kansas has received no satisfactory explanation as yet in published reports. With the consent of G. E. Condra, professor of geography and conservation at the University of Nebraska, I call attention to his oral statement that in the southeastern part of Nebraska granite was found at a depth of five hundred feet from the surface and penetrated for a depth of a thousand feet. This great mass of granite lies between southwestern Iowa and the oil fields further southwest, and, whatever other conditions are involved, bars underground circulation through formations that farther southwest are oil-bearing.

Border of the Missouri stage.—North of the fault plane (the upthrow side) erosion has given the east-west trend of the Missouri stage in Guthrie County. South of the fault plane (the downthrow side) the base of the Missouri stage extends far to the east. The extension to the eastward is thus not simply an uneroded mass of a highland region, as formerly supposed, but an uneroded portion left protected on the downthrow side[3] of a fault plane. Still further to the northeast, even to the "Driftless Area," along the general direction of the Thurman-Wilson fault may be noted east-west extensions of the various formations as mapped, as if the effect

[1] J. E. Todd, "On the Folding of the Carboniferous Strata in Southwestern Iowa," *Proc. of the Iowa Acad. of Sci.*, I, Part I (1889), 61; also XIII (1906), 184.

[2] G. L. Smith, "Carboniferous Section of Southwestern Iowa," *Iowa Geol. Surv.*, XIX (1909), 612.

[3] No one has as yet determined whether or not a continuation of Keyes's Cap-au-Gres fault bounds the eastern side of the Missouri stage in Iowa. He describes the fault as extending from Leon, Iowa, southeast to Vincennes, Indiana, but he gives no data with reference to the Iowa end of the line ("Extent and Age of the Cap-au-Gres Fault," *Proc. of the Iowa Acad. of Sci.*, XXIV [1917], 61).

of the disturbance were a factor in determining surface distribution well across the state. Investigation has not, however, by the writer been extended in the field to this part of the state.

AGE OF THE FAULT

Since the Dakota sandstone lies on both sides of the fault plane and rests on the truncated surface of various strata of the Missouri stage with no evidence of a fault scarp detected beneath the Dakota sandstone, it appears that the faulting began in the interval between the deposition of the Missouri stage and the deposition of the Dakota stage, that the fault scarp was well removed before the subsidence that accompanied the deposition of the Dakota sandstone, and that any additional faulting has not been very pronounced since that time. That there has been some later movement is possible, since at Crystal Lake shale included between the sandstone strata is found to dip in the general direction of the dip of the limestone (Missouri). If there was any movement along the fault plane any escarpment that formed at the surface of the sandstone has since been removed by erosion.

Variations in dip of the sandstone that correspond to variations in dip of the limestone along the fault plane have not been detected. It therefore appears from this argument also that about all faulting with accompanying disturbance[1] was completed before the Dakota sandstone was laid down. In this interval of time there was in the interior and eastern United States one marked period of disturbance, the Permian. In distant regions (Appalachian and Ouachita) the faulting was of the reversed type. Here it is of the normal type. The reversed faulting of the Permian may have been accompanied or followed by relaxational movements in the same or the next period. To this interval of time (Permian-Triassic) it at present seems necessary to refer the major part of the faulting, and perhaps all of it.

[1] From a study of the joint planes it also appears that the jointing in the Missouri stage is related to the faulting and to the uplift toward the northeast (Permian-Triassic), while the jointing in the sandstone is related to the uplift toward the northwest (post-Cretaceous), though affected by the presence of the fault plane and the joint planes, and also affecting those planes.

Reviews

The Geology of South Australia. By Walter Howchin. Pp. xvi +543. Figs. 330 and geological map. Adelaide: Government Printer, 1918.

Hitherto there has been no book which treated geologic processes and the general principles of geology from the Australian standpoint, although *The Geology of New South Wales* by Süssmilch may be cited as an admirable text on the historical geology of that interesting state. A feeling that there was need for a work on general geology with illustrations drawn from Australia has led to the present volume.

This volume is in two divisions. The first portion, which makes up more than half of the book, deals with geologic processes, the materials of the earth, and dynamic principles; the second portion outlines the historical geology of South Australia. While limited space precludes an exhaustive treatment of geologic principles, the reader nevertheless finds a great deal of well-illustrated material within these pages. The examples, illustrations, and concrete facts, taken largely from the Australian continent, come with a special freshness to the geologist of the Northern Hemisphere, to whom they are largely new and decidedly welcome.

A few points of dissent may be noted. The author's classification of the different forms of glacial deposits is perhaps not altogether orthodox from the viewpoint of others, as may be illustrated by the following statement, which appears under the heading of "Unstratified Glacial Deposits," on pages 146–47: "Subglacial streams wear irregular channels through the ground moraines, and when the ice disappears irregular ridges or mounds of drift are scattered over the valley bottom and are known as eskers, in Iceland; kames, in Scotland; osars, in Sweden; and drumlins, in America." On page 215, below a diagram illustrating slaty cleavage in a much-folded section, the statement is made that "cleavage planes preserve an exact parallelism and identical strike over wide areas, and are independent of the foldings of the rock as well as the bedding planes." Instead of being independent of the folding, flow cleavage has recently been shown to be developed parallel

to the axial planes of the folds, and to afford one of the prettiest keys to the interpretation of the larger units of structure in areas of complexly deformed rocks.

The second half of the volume, upon geologic history, brings out the fact that fewer geological systems are represented in South Australia than in any other Australian state, for the reason that a few systems cover a great extent of the country to the exclusion of the others. No Silurian, Devonian, or Triassic beds have been recognized, and Eocene beds have not as yet been definitely determined.

Among the most important systems are the Cambrian and the Permo-Carboniferous, in which occurred the very remarkable glaciations for which South Australia has become famous. The Cretaceous beds which surface a very considerable portion of South Australia form what is believed to be the greatest artesian basin in the world, yielding an abundant supply of usable water that is of the greatest economic importance in the development of some of the driest parts of Australia. These advantages, however, are shared with New South Wales, Queensland, and the Northern Territory. Following the discussion of each period in South Australia is a brief description of that system in the other Australian states.

The illustrations are good, and the book should prove useful to the working geologist outside of Australia as well as to the Australian student.

R. T. C.